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In Response to:
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Data Requirement A012

HELICOPTER NIGHT VISION SYSTEM SIMULATION EVALUATION PHASE III FINAL REPORT

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FOREWORD

This report is submitted to the Naval Air Development Center, Warminster, Pennsylvania, 18974, by Martin Marietta Corporation, Orlando Aerospace, in response to CDRL A012 of Contract N62269-80-C-0346.

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1.0 INTRODUCTION

The United States Marine Corps is presently developing and evaluating design requirements for a Helicopter Night Vision System (HNVS) effort to improve transport helicopter low-level night and reduced visibility capabilities. State of the art forward looking infrared (FLIR) systems make it possible for transport helicopters to conduct missions under conditions that would normally preclude operations.

The transport mission requires the transport helicopter to fly at extremely low altitudes at the highest speed possible. Pilots must also approach and land in unimproved landing zones. Personnel and equipment must be quickly off-loaded because the aircraft must depart to permit landing of the remainder of the formation. The mission must be accomplished day and night and in adverse weather conditions.

The HNVS concept, as shown in Figure 1-1, is centered on a FLIR mounted on the forward section of the assault helicopter. The FLIR imagery is provided at panel mounted displays (PMDs) or helmet mounted displays (HMDs) for the pilot and copilot. The total system will be designed to enable the mission to be performed safely with a minimal workload for the pilot and copilot. The FLIR will permit the pilot to operate under conditions of total darkness. Flight symbology is super-imposed on the FLIR imagery to minimize the pilot's and copilot's scan patterns. In addition, support avionics such as a self-contained navigation system, radar altimeter, aircraft transducers, central computer, and control panels are also required.

Preliminary system analysis and definition was completed prior to initiation of this simulation effort and was presented in OR-0930-AW, "Operational Requirements, Helicopter Night Vision Systems," dated 12 April 1977, and "Operational Effectiveness Analysis for the Helicopter Night Vision System," dated 30 September 1978. Phases I and II of the CH-53 Night Vision System Simulation were completed, and the results are reported in References 3, 4, and 5.

1.1 Objective

The current evaluation, Phase III, was conducted in accordance with the plans described in the HNVS Simulation Test Plan Task Report (Reference 7). The objective of this evaluation was to conduct a simulation program to obtain human factors data relating to the conduct of low-level Marine transport helicopter operations using night vision sensors. These data are to be used as inputs for the design of a candidate HNVS and to formulate a data base for additional definition and verification of the HNVS concept through planned flight tests.

1.2 Scope

Prior simulation evaluations (References 3, 4, and 5) have addressed human factors issues and sensor requirements with regard to sensor imagery, symbology formats, navigation and landing aids, failure modes, cockpit procedures, integration of cockpit controls and displays, and the effect of these on aircrew workload and performance. These evaluations concentrated primarily on basic system design parameters and aircrew interaction during the enroute portion of the transport mission. Results of Phase I and II evaluations indicated that a gimballed sensor, Doppler navigation system, and single FOV were required to complete the enroute mission requirements. Substantial changes in symbology were introduced as a result of pilot comments and performance. These configuration and symbology changes served as the baseline for the current evaluations.

This research outlines the present simulation evaluations that further expand, verify, and refine the data base to include the approach and landing phase of the mission. The program consisted of a simulation hardware and software development phase, a checkout phase, and three experimental evaluations. These evaluations, described in detail in section 4.0, were conducted in accordance with the following schedule:

1 Approach and landing: symbology; 10 January to 22 February 1981

2 Approach and landing: FOV; 27 February to 26 March 1981

3 HMD-PMD evaluation, with CDU; 24 April to 8 July 1981.

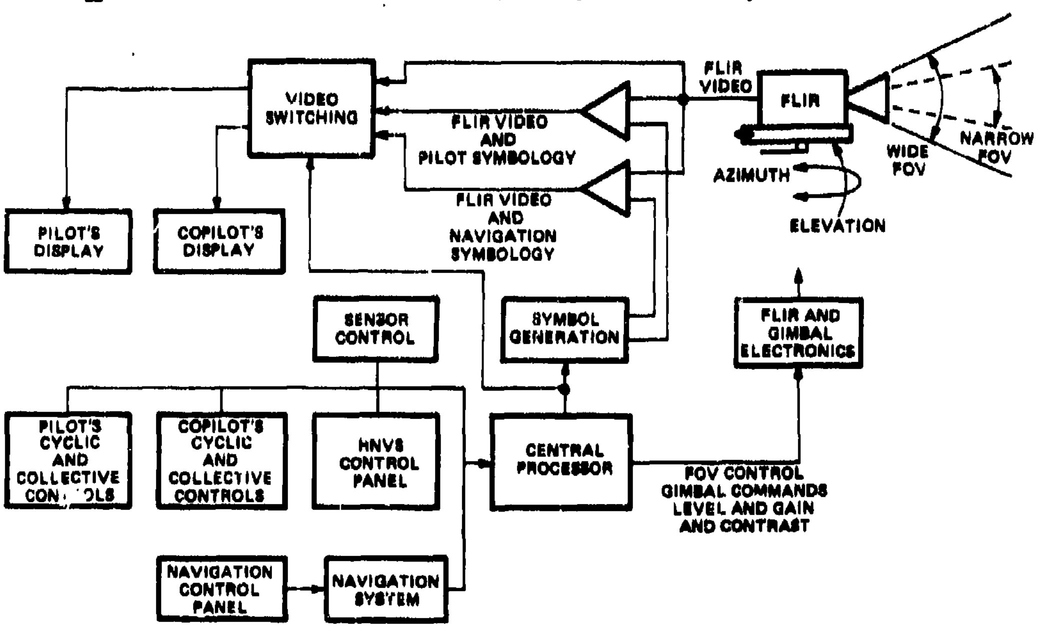

Figure 1-1. HNVS System Concept

2.0 SIMULATION HARDWARE AND SOFTWARE DEVELOPMENT

A number of developments in simulation hardware and software were required to accomodate the evaluation requirements. Each of the developments is discussed separately below.

2.1 Cockpit

The CH-53D cockpit constructed under contract N62269-79-C-0317 was used for this simulation. The complete Government furnished equipment (GFE) list is shown in Appendix A. The exterior view of the cockpit is shown in Figure 2-1, which depicts the mounting of the cockpit on the six-degree-of-freedom motion base. The instrument panel, shown in Figure 2-2, was configured in accordance with NADC drawing TE21733-B. The cockpit lighting is in accordance with NADC cockpit lighting memo of 28 August 1980. The center console was configured as shown in Figure 2-3. A helmet mounted display and sight system, described in section 2.3.4, was installed in the cockpit. Additional cockpit wiring was installed to accomodate the new cockpit configuration.

2.2 Aerodynamic and Flight Control Model

The special purpose rotorcraft simulator (SPURS) is a full force and moment simulation of the CH-53D helicopter valid over the speed range from approximately 30 knots rearward flight to forward airspeeds in excess of 160 knots. The automatic flight control system (AFCS) is modelled on analog computers and contains the stability augmentation system (SAS) and outer loop attitude and heading hold modes.

2.3 Controls and Displays

2.3.1 Controls

Significant changes from the Phase I and II cockpit configuration were made in the center console control functions. The HNVS and Infrared Detection System (IRDS) control panels available during Phase II were replaced with new units. A Helicopter Integration System (HIS) Fail panel and two Navigation/Electronic Attitude Director Indicator (NAV/EADI) panels were added. These new panels are presented in Figures 2-4 through 2-7 and in the center console (Figure 2-3). The cyclic and collective controls are identical for pilot and copilot operation and are shown in Figures 2-8 and 2-9. All switch functions are as labeled on these drawings and their interaction in the simulator was specified in the NADC document (Reference 1) except for the "Hover Position" switch on the cyclic stick grip (Figure 2-8 . This switch is used to enable and update the hover position symbol (number 14A in Figure 2-11).

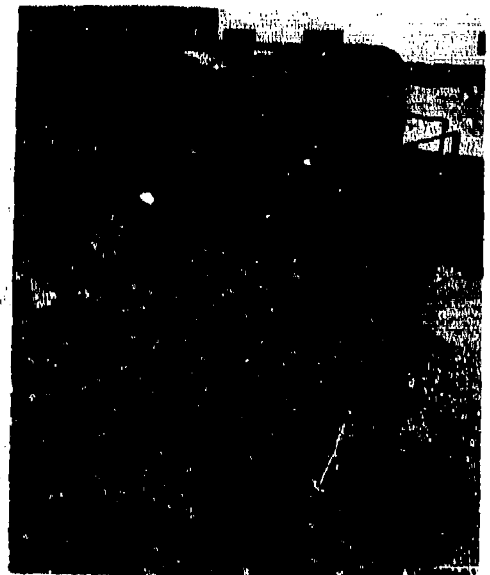

Figure 2-1. Cockpit on Motion Base

Figure 2-2. Instrument Panel

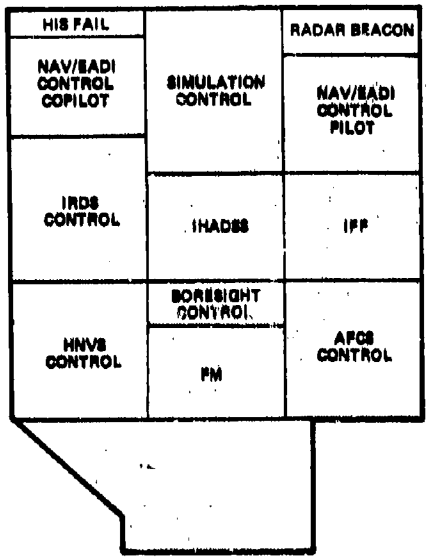

Figure 2-3. Center Console

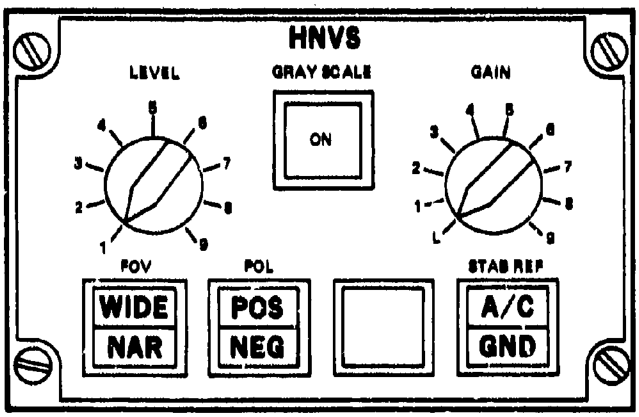

Figure 2-4. HNVS Control Panel

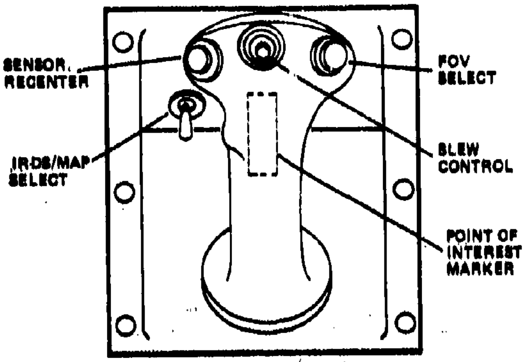

Figure 2-5. IRDS Control Panel

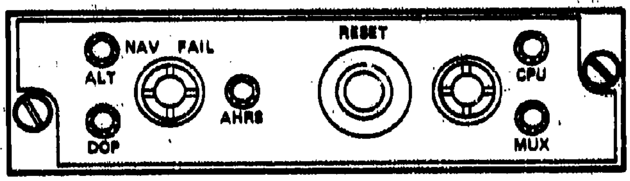

Figure 2-6. HIS Fail Panel

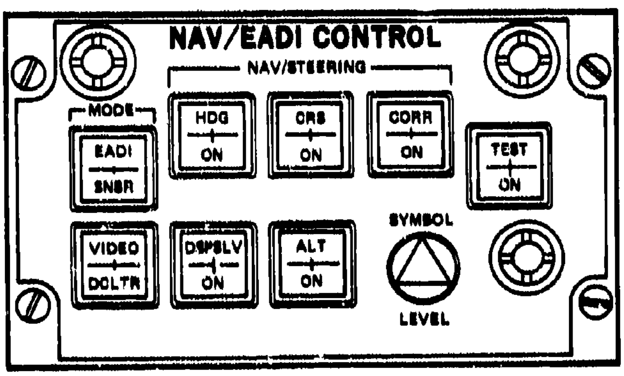

Figure 2-7. NAV/EADI Panel

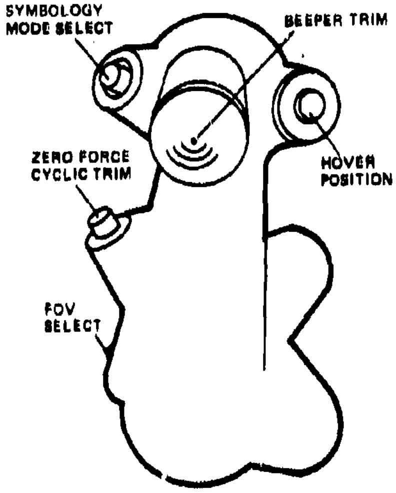

Figure 2-8. Cyclic Control

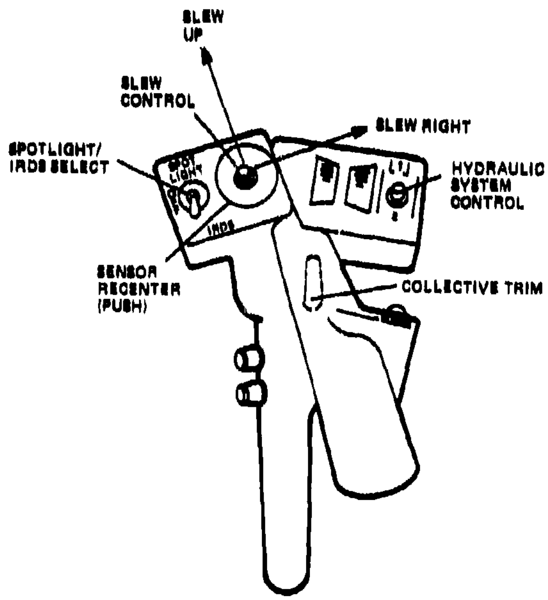

Figure 2-9. Collective Control

2.3.2 Sumbology

The symbol generator for the Electronic Attitude Director Indicator (EADI) provided the primary source of flight and sensor data presented to the pilot on the PMDs. The EADI provided the aircrew with piloting information as well as sensor data. Independently controlled PMDs were provided for the pilot and copilot. Mode control for these displays was provided by the pilot and copilot NAV/EADI control units. The interface requirements for the symbol generator software and related EADI display parameters were specified in Reference 1.

Figures 2-10 through 2-13 show symbology formats on the pilot and copilot PMDs.

2.3.3 Control Display Unit (CDU)

The CDU (Figure 2-14) used in the simulation was the primary man-machine interface for navigation initialization and mode control. The CDU consists of a CRT display, master function switches, line keys, and an alphanumeric keyset. The CDU enabled the copilot to view either the results of alphanumeric functional inputs or a tactical plot showing fly-to-point data, reference points, and aircraft position along a projected course. The flight plan, as shown in Figure 2-15, contains two pages of five fly-to-points (FTPs) each and one page of reference points. The line keys of the flight plan include functions to capture and delete an FTP or landing zone, entry of new points, or designation of a new landing zone. The CDU tactical map (Figure 2-16) is configured according to the FTP and reference point coordinates in the flight plan file. The display scale range can be decreased or increased by the operator. A helicopter symbol marks the helicopter position and travels from point to point with reference to the flight corridors. The display of the direct-to navigation function is similar to the flight-plan (Figure 2-15) with the message "DIRECT TO" on the bottom of the screen. This function provides guidance when deviating from the preprogramed flight plan.

2.3.4 Helmet Mounted Display (HMD)

A HMD system was installed in the cockpit. The Integrated Helmet and Display Sight System (IHADSS) is shown in Figure 2-17. The sight determined the pointing directions of the pilot line of sight (LOS), and the HMD provided the pilot and copilot with the collimated video displays. The IHADSS was used to slave the HNVS sensor to the pilot LOS and display the HNVS imagery to both pilot and copilot HMDs. Figure 2-18 shows the IHADSS control panel.

To provide the pilot with needed aircraft reference during sensor operation using the HMD, the sensor pointing symbol represented the nose of the aircraft relative to the pilot's LOS. This was used only on the HMD and the symbol moved relative to the pilot's head movements. Remaining symbology, from that available on the PMDs, was unchanged.

SYMBOL NAME

1 AIRCRAFT SYMBOL
2 HORIZON/PITCH BARS
3 RADAR ALTITUDE (ANALOG)
4 RADAR ALTITUDE (DIGITAL)
5 VELOCITY VECTOR
6 IR SENSOR
7 TORQUE
8 GROUNDSPEED/AIRSPEED
9 AIRCRAFT HEADING
10 NAVIGATION STEERING
11 DISTANCE TO GO
12 ALTITUDE REFERENCE BAR
13 VERTICAL SPEED
15 TIME TO GO
16 AIRSPEED INDICATION
17 POINT OF INTEREST
18 FAILURE WARNING INDICATOR
19 CORRIDOR BAR

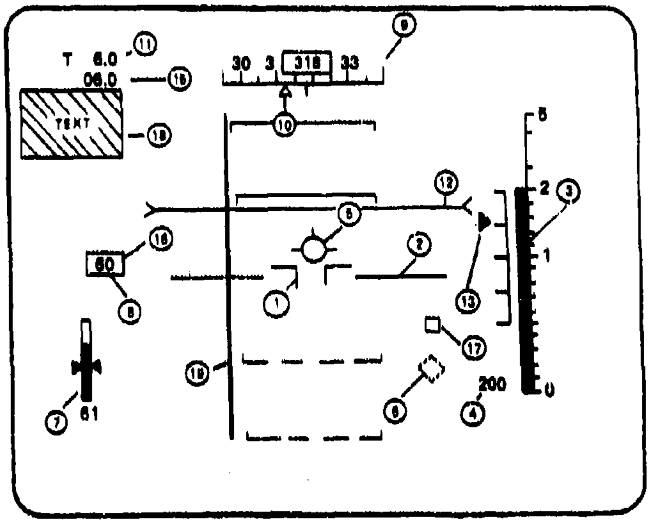

Figure 2-10. Flight Symbology Format

SYMBOL NAME

1 AIRCRAFT SYMBOL
2 HORIZON BARS
3 RADAR ALTITUDE (ANALOG)
4 RADAR ALTITUDE (DIGITAL)
6 IR SENSOR
7 TORQUE
8 GROUNDSPEED/AIRSPEED
9 AIRCRAFT HEADING
10 NAVIGATION STEERING
11 DISTANCE TO GO
12 POSITION BOX
13 VERTICAL SPEED
15 TIME TO GO
16 AIRSPEED INDICATION
17 POINT OF INTEREST
18 HOVER VELOCITY
19 HOVER ACCELERATION

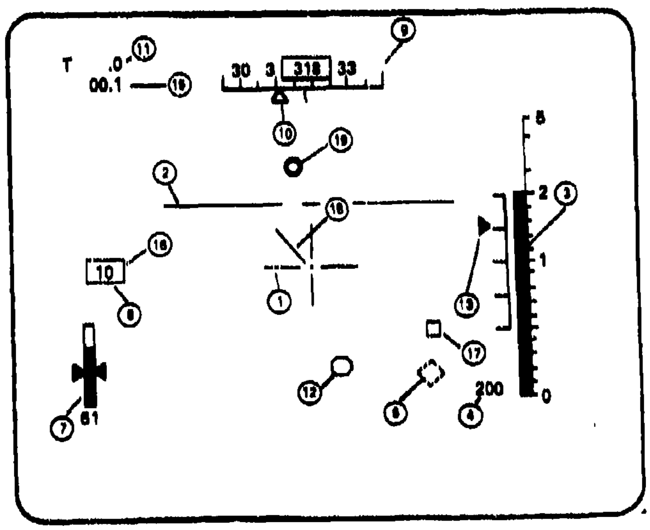

Figure 2-11. Hover/Transition Symbology Format

SYMBOL NAME

1 AIRCRAFT SYMBOL
2 HORIZON/PITCH BARS
3 RADAR ALTITUDE (ANALOG)
4 RADAR ALTITUDE (DIGITAL)
5 VELOCITY VECTOR
6 IR SENSOR
7 TORQUE
8 GROUNDSPEED/AIRSPEED
9 AIRCRAFT HEADING
10 NAVIGATION STEERING
11 DISTANCE TO GO
12 NAVTOLAND WINDOW
13 VERTICAL SPEED
15 TIME TO GO
16 AIRSPEED INDICATION
17 POINT OF INTEREST
18 WINDOW BOX REFERENCE BRACKETS

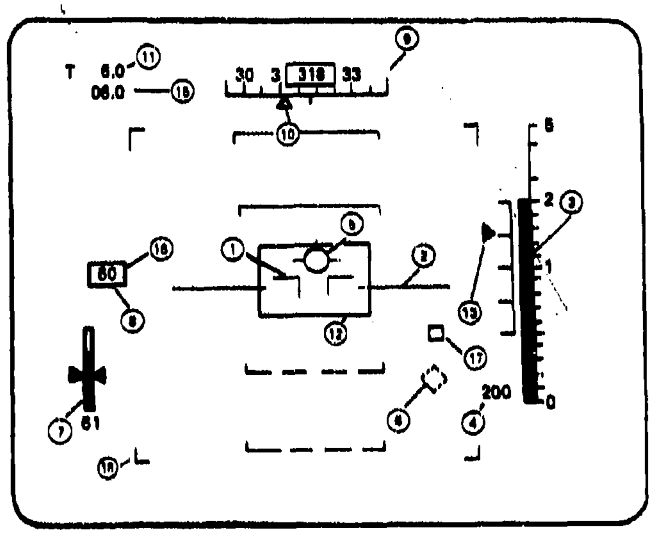

Figure 2-12. Window Box Symbology Format

SYMBOL NAME

1 AIRCRAFT SYMBOL
3 RADAR ALTITUDE (ANALOG)
4 RADAR ALTITUDE (DIGITAL)
6 IR SENSOR
7 TORQUE
8 GROUNDSPEED/AIRSPEED
9 AIRCRAFT HEADING
10 NAVIGATION STEERING
11 DISTANCE TO GO
13 VERTICAL SPEED
15 TIME TO GO
16 AIRSPEED INDICATION
17 POINT OF INTEREST
18 HOVER DRIFT
19 HOVER VELOCITY

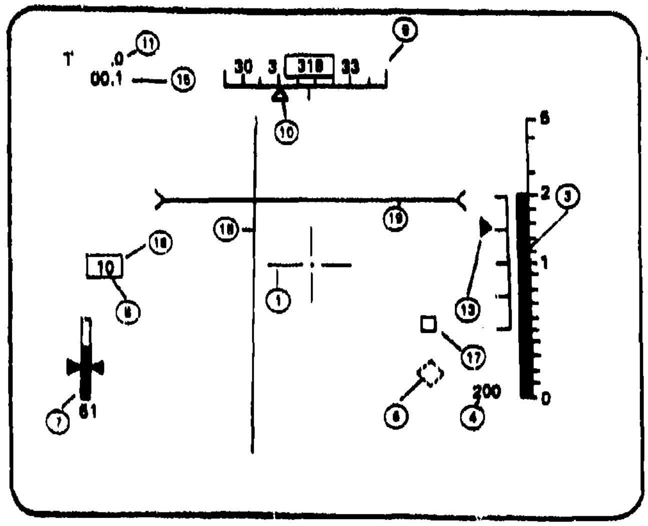

Figure 2-13. Hover Meter Symbology Format

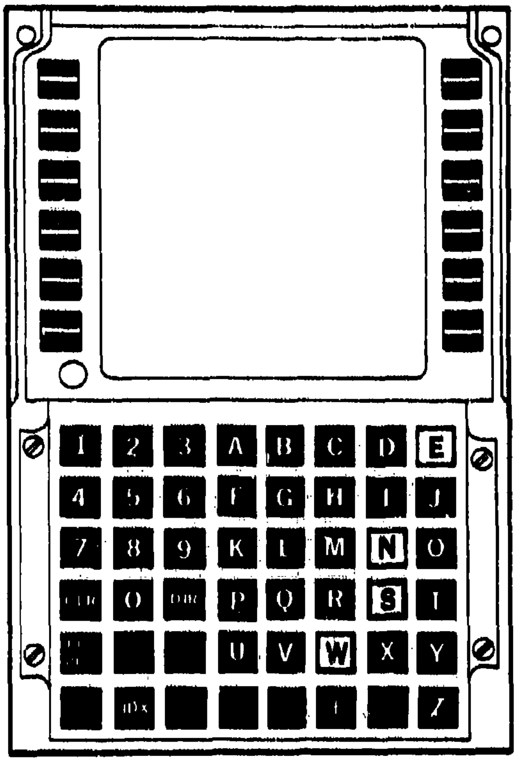

Figure 2-14. Control Display Unit

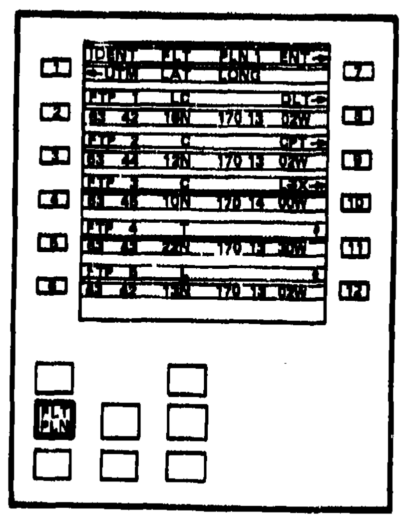

Figure 2-15. CDU Flight Plan Master Function

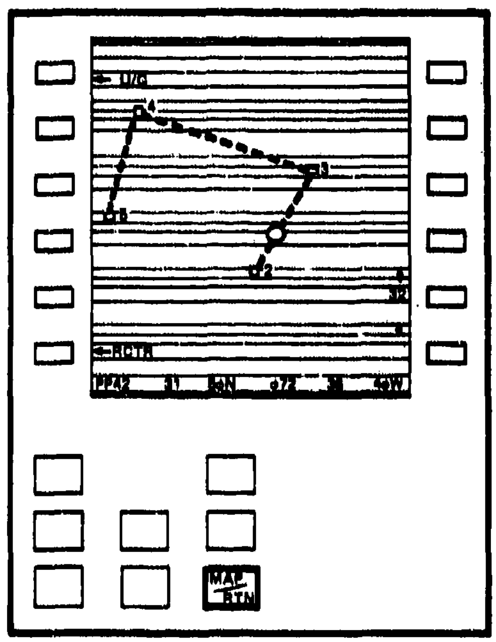

Figure 2-16. CDU Tactical Map Display

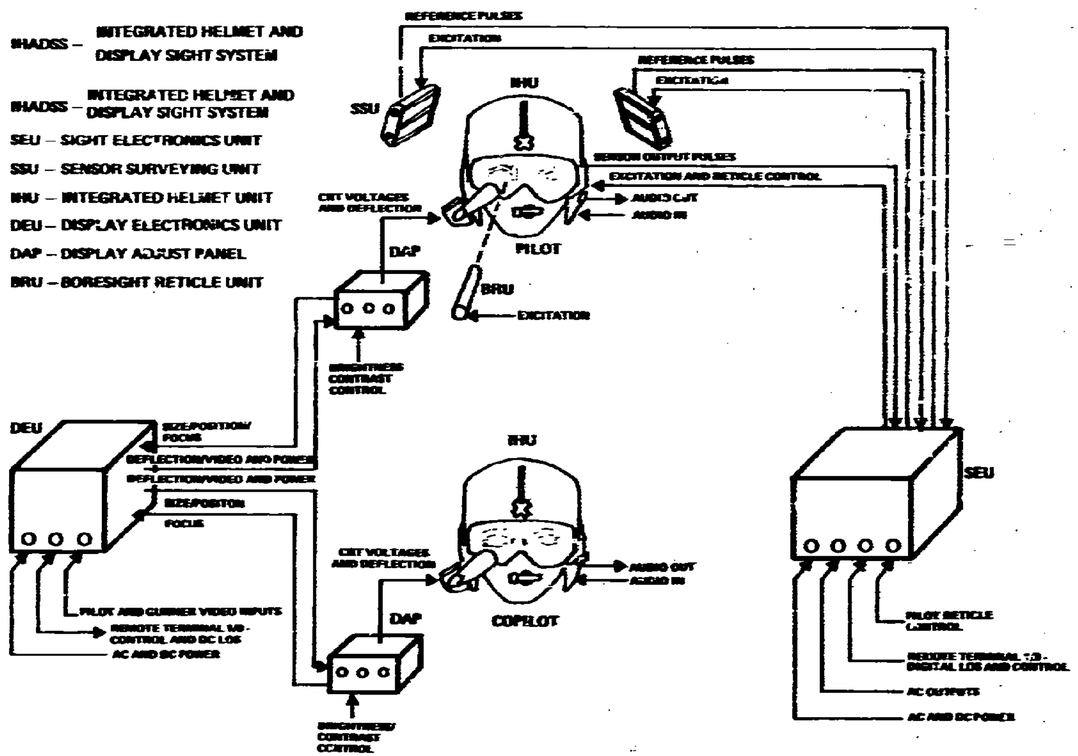

Figure 2-17. IHADSS System Diagram

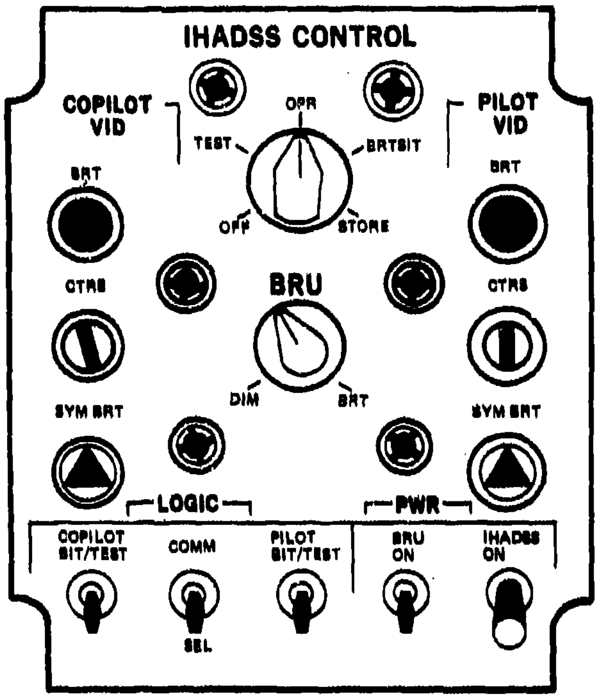

Figure 2-18. IHADSS Control Panel

2.4 Simulation

All simulation work was performed at the Simulation and Test Laboratory (STL) Man-in-the-Loop facility. This facility is fully described in "Final Cockpit and Software Preparation Task Report," OR 15,647-2, dated March 1981 (Reference 2).

The terrain model, as shown in Figure 2-19, was modified with removable overlays to facilitate the approach and landing studies. Definitive landing zones and appropriate enroute sections of the terrain board were reconfigured from a 1200:1 to a 240:1 scaling factor to provide for lower flight levels, sensor usage data, and precise maneuvering capability in confined landing areas. This improvement allowed realistic visual presentations down to approximately 25 feet above ground level. The highly detailed scale required a higher pilot workload to precisely maneuver the aircraft than has been experienced in previous simulations. This higher workload was experienced in the pilot's requirement for increased attention to piloting tasks. The confined landing zones required exact piloting maneuvers to land on the prebriefed touchdown point. The additional realism forced the subject pilots to increase their airspeed attention as compared to previous simulations.

The landing zones shown in Figures 2-20 through 2-22 represented an unimproved landing area, a slightly improved area, and an embassy compound. Additional landing areas included open fields and small forest clearings at the 240:1 scale.

2.5 Systems Checkout

The systems checkout activity validated the simulation. Test pilots from the Naval Air Test Center flew simulated missions and evaluated simulator operation and fidelity. This checkout served as inputs for simulation modifications.

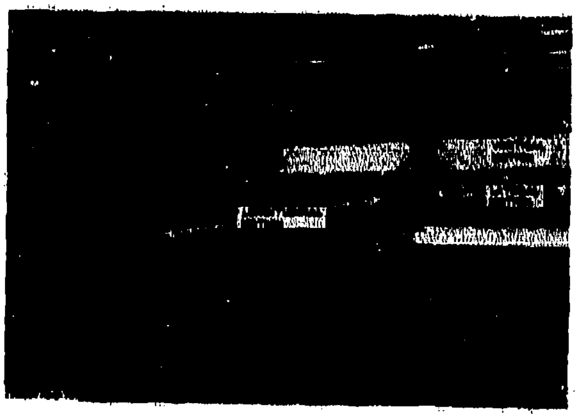

Figure 2-19. Terrain Model

Figure 2-20. Unimproved Landing Zone

Figure 2-21. Slightly Improved Landing Zone

Figure 2-22. Embassy Landing Zone

3.0 FACILITY DESCRIPTION

3.1 General Description

The Man-in-the-Loop simulation system facility supported the CH-53D HNVS program. It consisted of the following major elements:

1 Hybrid computing system

2 Motion base system

3 Translational system optical probe

4 Television system

5 Programmable display generator (PDG)

6 Control loading system.

3.1.1 Hybrid Computing System

The simulation was controlled by a hybrid computing system, consisting of two Sigma 5 digital computers, three EAI 231-RV analog computers and appropriate instrumentation, and interface and peripheral equipment. The computer arrangement controlled the aerodynamics, processed position commands to the sensor probe and TV, handled operational mode logic and switching functions, generated commands to position symbology on the visual displays, and stored performance data.

The simulation program used the SPURS developed by Paragon Pacific, Inc. This unit was designed to model helicopter aerodynamics and was configured to simulate a CH-53D aircraft. The pilot's controls were input to a primary flight control model and augmented with SAS and AFCS models. These were input as the swash plate commands for the main rotor, the collective pitch of the tail rotor, and engine controls.

3.1.2 Motion Base System

The motion base system provided a means to move the cockpit in six degrees of freedom as commanded by the pilot-actuated flight controls. It, in turn, provided acceleration cues to the pilot as the aircraft was flown. The motion base drive equations were modelled on two analog computers.

3.1.3 Translational and Optical Probe Systems

The three-dimensional terrain model and its motion relative to the optical probe system provided the pilot with visual translational cues via cockpit displays. The model was moved along a rail system perpendicular to and under a vertically actuated beam providing the longitudinal and vertical movement of the aircraft. A carriage supporting the optical probe was moved across the beam to provide the lateral aircraft movement. The optical probe, in turn, provided the three angular degrees of freedom of aircraft movement. The translations, velocities, and accelerations were scaled according to the terrain model scale of 1200:1 with a minimum scaled altitude of approximately 125 feet or 240:1 with a minimum scaled altitude of approximately 25 feet.

3.1.4 Television System

A 525 line high resolution, monochrome camera system was used with the optical probe to provide the pilot with a view of the terrain as the aircraft was controlled. It provided two FOVs, 50 and 25 degrees. White hot IR imagery was generated by reversal of the normal video signal.

3.1.5 Programmable Display Generator (PDG)

A PDG was used to generate symbology for the cockpit displays. The PDG generated two independent raster displays (pilot and copilot), which were then mixed with the 525 line television signal containing the scene video. The symbology was available in either a white or black format, and the intensity was controlled from the cockpit. The PDG was interfaced to, and controlled by, the Sigma 5 digital computer for dynamic movement of the symbology as the pilot commanded the aircraft.

3.1.6 Control Loading System

The control loading system reproduced the pilot's flight control forces for the simulator cyclic stick and pedals. This system was a three-axis unit providing pitch and roll cyclic stick and rudder pedal forces. The trim system permitted either beeper trim or trim release from the cyclic controls. The pedals were outfitted with pedal switches for interaction with an AFCS heading hold function.

3.2 Simulation Facility Limitations

The simulation facility visual perception attitude limitation of approximately 125 feet at the 1200:1 scaling factor was improved after completion of the Phase II experiment. This 1200:1 scaling factor provided mountainous terrain to traverse during Phase II data runs and was adequate for fast moving, higher flying, fixed wing simulations. At slower helicopter speeds and at much lower altitudes, however, the 1200:1 scale factor provided less detailed terrain relief and less obstacle avoidance feedback requirements because of the heavily concentrated forested areas than would

be expected in a real world mountainous and forested contour flight environment. This visual perception altitude limitation was improved by remapping the terrain model surface and incorporating enroute highly detailed 240:1 model overlays and landing zones. This scaling factor was designed specifically for helicopter simulations and provides a realistic, low altitude, highly detailed flying environment. The visual perception altitude limitation was reduced to approximately 25 feet above ground level (AGL), the heavily concentrated forested areas were replaced with strategically placed, individually detailed trees (averaging approximately 80 feet in height), and high workload, realistic landing zones were developed.

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4.0 EXPERIMENTAL DESIGN

4.1 Introduction

Prior simulations addressed basic system configuration issues. In the Phase I evaluation, it was determined that a self-contained (Doppler) navigation system was a requirement for the mission, and several refinements were made in display symbology (References 3 and 5). In the Phase II evaluation, recommendations were made regarding the need for a gimballed sensor and a single FOV (References 4 and 5). Other recommendations were made with regard to symbology changes, display changes, and crew training adjustments. These findings are reported in detail in the final report (Reference 5).

The simulation data conditions required the person sitting in the right seat of the cockpit to always be the pilot in control of flying the aircraft. The person in the left seat was always the copilot/navigator. In discussions of the procedures and research results, this condition must be considered. All of the participants were operational Fleet Marine pilots, but crews were comprised of designated pilot and copilots with all participants having equal participation in both roles.

4.2 Approach and Landing Symbology Evaluation

To determine the effects of symbology on crew performance during approach and landing, four symbol sets were used. The flight symbology set developed during Phases I and II and modified for the flight test aircraft was used as a baseline symbology format; the hover/transition symbology (hover) set including hover velocity vector and acceleration cue; the window box symbology set; and a cross hair symbology (hover meter) set similar, except for sensing reversal, to current hover indicators used on Doppler-configured Navy helicopters. These symbology sets are shown in Figures 2-10 through 2-13 in section 2.3.2. Each symbology set was evaluated in landing zones with four levels of difficulty based on zone diameter. The largest landing zone (level 4) equalled 4.5 rotor diameters or more, the level three zone was 3.5 to 4.4 diameters, level two was 2.5 to 3.4 diameters, and the smallest landing zone (level 1) was 2 to 2.4 diameters. The evaluation consisted of a 4 by 4 study or 16 treatment combinations. To reduce variance and increase sensitivity, a repeated measures design was used. Variables were examined with 12 Fleet Marine pilots as subjects.

A Greco Latin Square design allowed order effects to be evenly distributed across all subjects and treatments. Treatment combinations resulted from the data matrix in Figure 4-1.

		LANDING ZONE SIZE (DIFFICULTY LEVEL)			
		1	2	3	4
SYMBOLOGY SET	FLIGHT				
	HOVER				
	WINDOW BOX				
	HOVER METER				

Figure 4-1. Experimental Matrix for Approach and Landing Symbology Evaluation

4.3 Approach and Landing Field of View Evaluation

Three treatment FOV conditions were used to determine their effect on performance during approaches and landings. The FOV treatments were: wide (50 degrees), narrow (25 degrees), and dual (50 degrees and 25 degrees under pilot control). Each FOV was evaluated in landing zones with the same four difficulty levels. The symbology set found most effective in the symbology evaluation was used throughout this portion of the study. The evaluation required a 3 by 4 study or 12 treatment combinations. Again, a repeated measures design was used. Eight Fleet Marine pilots were used in this evaluation. The data matrix for the FOV evaluation is shown in Figure 4-2.

4.4 Approach and Landing PMD-HMD Evaluation

To determine the effects of display combinations on crew performance during approach and landing, three treatment conditions were tested: pilot and copilot using PMDs, pilot using an HMD and copilot using PMD, and pilot and copilot using HMDs. Each combination was evaluated in landing zones with two difficulty levels. The large zone was 3.5 rotor diameters (difficulty level 2) or more, and the small landing zone was 3.4 rotor diameters or less (difficulty level 1). The evaluation required a 3 by 2 study or 6 treatment conditions. Twelve Fleet Marine pilots participated in this phase.

The data matrix for this evaluation is shown in Figure 4-3. Again, treatment combinations were counterbalanced through a Greco Latin Square.

4.5 Enroute PMD-HMD and CDU Evaluation

The enroute evaluation was conducted at the 1200:1 scale in an effort to determine the effects of display combinations on performance during low level flight on longer routes requiring substantial navigation workload. An enroute course change was added as a variable to examine the difficulty of inserting a change in the route midway in a mission. Two route changes were included (hard: mountainous terrain; and easy: flat terrain). This evaluation required a 3 by 2 by 2 study, and Figure 4-4 contains the data matrix. The 12 pilots used in the approach and landing HMD/PMD evaluation participated in this evaluation. Random conditions were used such that pilots could not predict course changes. Order effects were controlled through use of a Greco Latin Square.

4.6 Virtual Head Up Display (HUD) Evaluation

It was anticipated that copilots might find it objectionable or become disoriented with the HMD continually presenting the sensor imagery as the copilot scanned instruments inside the cockpit. Consequently, a virtual HUD presentation was included. As the copilot turned his helmet away from a 30 by 40 inch window located straight ahead, the image moved off of the HMD as if he were looking at a stationary HUD. The experimental designs were identical to those in sections 4.4 (approach and landing) and 4.5 (enroute) with the treatment conditions being pilot HMD and copilot PMD, pilot HMD and copilot HMD, and pilot HMD and copilot HMD with virtual HUD. This evaluation used four Fleet Marine pilots.

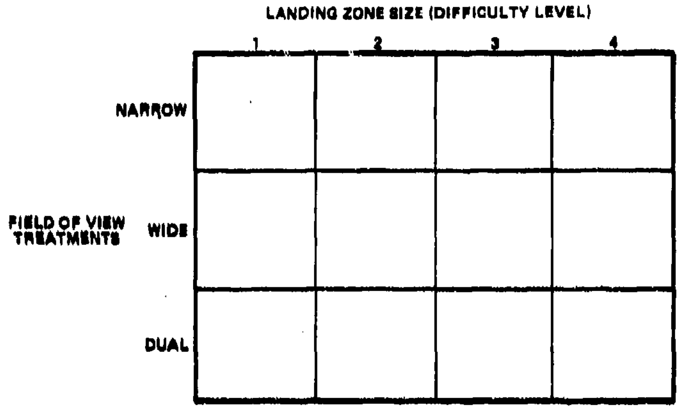

Figure 4-2. Experimental Matrix for Approach and Landing FOV Evaluation

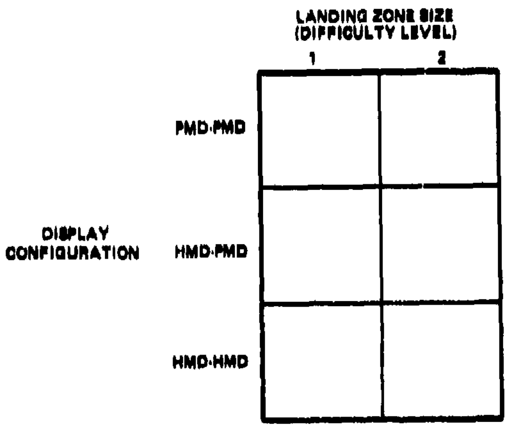

Figure 4-3. Experimental Matrix for Approach and Landing PMD-HMD Evaluation

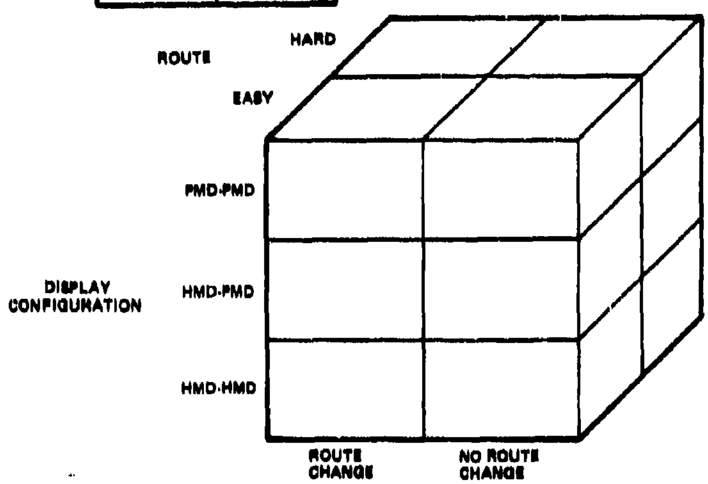

Figure 4-4. Experimental Matrix for Approach and Landing PMD-HMD-CDU Evaluation

4.7 Side Studies

Time permitted examination of several HNVS issues in addition to the primary research. These studies did not warrant full scale factorial treatment.

4.7.1 Radar Altitude Analog Scale

Several pilots in the previous phase had indicated a desire for changes in the radar altitude analog scale and digital readout at low altitudes. The purpose of this study was to determine the usefulness of removing the analog scale while using the hover symbology, and moving the digital readout to the midsection of the right hand side of the display. The digital readout was in units of 1 foot below 25 feet. Four Fleet Marine pilots evaluated these changes.

4.7.2 Landing without Simulated Crew Chief

On actual operational missions, especially night landings, pilots are assisted by their crew chief in positioning the aircraft in the landing zone. Crew chiefs verbally advise the pilot to move forward, backward, left, and right until rotors and tail are clear of obstructions and landing may be safely completed. In the approach and landing studies, the experimenter used a separate display to determine aircraft position in the landing zone. With this information, the experimenter was able to provide the subject pilots with the same verbal cues as those available from crew chiefs in an actual mission.

It was theorized that the simulated crew chief would reduce pilot reliance on symbology during landing. Therefore, pilots were forced to land in the smaller landing zone without the aid of the simulated crew chief, using only the gimballed sensor and symbolic information. These landings were observed to define the extent of sensor feedback given and the effects of symbology on landing. Four Fleet Marine pilots were used in this evaluation.

4.7.3 Symbology Attitude Sized to the 30 Degree Field of View Imagery

The purpose of this study was to determine what effects, if any, sizing the symbolic horizon and pitch ladders to the wide FOV would have on pilot ability to perform the mission scenario. The pitch ladders represented 5 degrees and 10 degrees, and the horizon indicator was placed on the infinity horizon of the image. Again, four Fleet Marine pilots participated.

4.7.4 Partial Ground Stabilized Sensor versus Aircraft Stabilized Sensor

It was theorized that stabilizing the sensor relative to the ground would reduce crew disorientation, especially during the final landing approach. The sensor for the ground stabilized mode was decoupled in

pitch but remained with the aircraft in roll and yaw. The pilot or copilot could command the sensor mode when the sensor was at the desired pitch angel by depressing the stabilization switch on the HNVS control panel (Figure 2-4). Four Fleet Marine pilots were used in this study.

5.0 EXPERIMENTAL PROCEDURES

5.1 Preliminary Briefings

Pilots were given an STL orientation, a system briefing, and an experimental briefing. These briefings provided subjects with general facilities information, simulation background, and experimental procedures and requirements. Additional information included cockpit control functions and symbology definitions and uses. After the briefings, pilots received a facilities tour and hands-on instruction in the cockpit regarding controls and symbology.

5.2 Training

The subject pilots were required to assimilate a large quantity of highly technical information. The training was designed so that the pilots obtained information in small amounts and were then allowed to practice this information until they obtained a foundation to facilitate further learning. Preliminary training progressed in this manner until all necessary information had been briefed and practiced.

5.2.1 Controls and Symbology

The conference room briefing included a handout of the control locations and functions plus symbology descriptions and functions. Pilot ground school was provided to facilitate learning prior to the cockpit familiarization phase. The hands-on cockpit familiarization allowed time to go over the handouts with the actual instrumentation. Each pilot was given approximately 20 minutes to manipulate the controls and see the appropriate symbology functions.

5.2.2 Integrated Helmet and Display Sight System (IHADSS)

Ground school for the IHADSS included a description of the background, purpose, system configuration, and boresight method. This description was given after the STL tour and cockpit familiarization. Pilots were given instructions on how to boresight the IHADSS and cautions regarding handling the HDU.

A representative from Honeywell fit each pilot with helmet liners. A properly fitting helmet is essential to the HMD, and this was accomplished prior to flight training. The experimentor assisted each pilot on initialization of the system prior to the first flight.

5.2.3 Control and Display Unit (CDU)

Pilots were given general CDU information as well as a step-by-step procedure for enroute course changes when applicable. The direct-to (DIR) master function key was described in detail and pilots reviewed the procedures handout prior to the first initialization. The CDU functions are described in section 2.3.3.

5.2.4 Flight Training

In all evaluations, pilots were given training routes to fly which used sections of the terrain model not used during data acquisition. This minimized memorization of terrain features in areas of data flights. The pilot groups progressed through fixed and motion-base familiarization flights and finally to training flight configurations which mirrored the data acquisition procedures. All experimental conditions in each evaluation were counterbalanced throughout the training sessions to prevent separate learning curves. Pilot learning was closely monitored to ensure trainee understanding.

The pilots reached a point in training when they stopped learning control functions, simulator operation, mission requirements, definitions of symbology, and other characteristics of the system. At this point their learning curve began to level off and performance improvements were a function of practice rather than additional learning. Crash rates due to erratic flight and misunderstanding of symbology and controls decreased, and flight altitudes and speeds became consistent. Touchdown information on drift and time also indicated improved performance. When all pilots in the group approached their learning asymptote, as evidenced in their performance, data collection commenced. This judgement was made by the experimenter and test conductor.

5.3 Data Collection

5.3.1 Briefings

Before each session of runs, pilots were briefed on the mission scenarios. Pilots were given area terrain maps in the order they were to fly them. The maps indicated routes with the checkpoints and landing zones identified. Additionally, 8 by 10 inch black and white reconnaissance photos of the landing zones with the inbound and outbound headings depicted were provided. Pilots were given time to study the routes prior to flight.

5.3.2 Procedures

The approach and landing studies emphasized the terminal phase of the mission and used the 240:1 scale. Each data run began 2 to 3 nmi from the landing zone. Pilots were instructed to remain below 100 feet above ground level (AGL) 90 percent of the time and fly at the fastest forward safe speed. They navigated using two checkpoints, made an approach and landed at the prebriefed location, lifted off and departed on an outbound heading. The simulated crew chief assisted in the landing phase only after a pilot verbal request and within 0.1 nmi from the landing point.

The enroute studies emphasized the navigation phase of the mission and used the 1200:1 scale. Each data run began approximately 15 nmi from the landing zone. Instructions were the same as in the approach and landing studies regarding staying below 100 feet AGL 90 percent of the time at the fastest safe speed. Pilots navigated using three checkpoints, made an approach and hovered over the designated landing point, and departed on an outbound heading. On preselected data runs, pilots were instructed (without warning) to divert to an alternate route.

5.3.3 Debriefings

The pilots participated in informal defriefing sessions at the conclusion of data run sets and completed extensive debrief questionnaires upon conclusion of the data sessions for all evaluations. The informal debriefing sessions and questionnaires were designed to obtain subjective information from the participants on relevant HNVS issues.

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6.0 PILOT PERFORMANCE RESULTS

The crew performance measures are shown in Table 6-I for approach and landing and Table 6-II for the enroute phase. The approach and landing phase is concerned with the terminal portion of the mission and the enroute phase with navigation performance. The data discussed in this section refers to the performance measures established in these tables.

TABLE 6-I

Pilot Performance Measures for Approach and Landing Evaluation (240:1 Scale)

MEASURE	INDEX
ALTITUDE (AGL) 1.5 TO 0.6 NMI FROM LANDING ZONE	MEAN DISTRIBUTION (10 FOOT INTERVALS) 0 TO 350 FEET
GROUND SPEED 1.5 TO 0.6 NMI FROM LANDING ZONE	MEAN DISTRIBUTION (10 KNOT INTERVALS) 0 TO 130 KNOTS
SENSOR FIELD OF REGARD 1.5 TO 0.6 NMI 0.6 NMI TO TOUCHDOWN LIFTOFF TO 1.0 NMI	MEAN AZIMUTH AND ELEVATION DISTRIBUTION (5 DEGREE INTERVALS)
FIELD OF VIEW 1.5 TO 0.6 NMI 0.6 NMI TO TOUCHDOWN LIFTOFF TO 1.0 NMI	PERCENT OF TIME NARROW AND WIDE PERCENT OF PILOT OR COPILOT CONTROL
NARROW FOV COMMANDS 1.5 NMI TO TOUCHDOWN	MEAN DISTANCE DISTRIBUTION (0.1 NMI INTERVALS)
SWITCH ACTIVATIONS	ACTIVATION TIME (SECONDS)
RADIAL LANDING ERROR	DISTANCE IN FEET FROM SPECIFIED LANDING SPOT, PERCENT OF MAX ALLOWABLE ERROR
SETDOWN RATES	VELOCITIES AT SETDOWN IN FT/S X (LONGITUDINAL AIRCRAFT AXIS DRIFT) Y (LATERAL AIRCRAFT AXIS DRIFT) Z (VERTICAL AIRCRAFT AXIS DRIFT)
NUMBER OF CRASHES	GROUND IMPACT TREES OR OBSTRUCTIONS
LANDING TIME	TIME (SECONDS) BETWEEN 0.6 MILE AND TOUCHDOWN
AIRCRAFT STATUS (DISTANCE DISTRIBUTION)	STATUS AT 0.1 NMI INTERVALS STARTING AT 1.0 NMI INBOUND ENDING AT 1.0 NMI OUTBOUND GROUNDSPEED (KNOTS) VERTICAL SPEED (FT/MIN) RADAR ALTITUDE (FEET) PITCH (DEGREES) TIME (SECONDS) COLLECTIVE (PERCENT OF TORQUE)
AIRCRAFT STATUS (TIME DISTRIBUTION)	STATUS AT 2 SECOND INTERVALS LAST MINUTE BEFORE TOUCHDOWN FIRST MINUTE AFTER LIFTOFF GROUNDSPEED (KNOTS) VERTICAL SPEED (FT/MIN) RADAR ALTITUDE (FEET) PITCH (DEGREES) DISTANCE TO TD POINT (FEET) COLLECTIVE (PERCENT OF TORQUE)

TABLE 6-II

Pilot Performance Measures for Enroute Evaluations (1200:1 Scale)

MEASURE	INDEX
ALTITUDE (AGL)	DISTRIBUTION (10 FOOT INTERVALS) 0 TO 200 FEET
GROUNDSPEED	MEAN DISTRIBUTION (10 KNOT INTERVALS) 0 TO 130 KNOTS
CHECKPOINT ARRIVAL LANDING ZONE 1.0 NMI ARRIVAL	TIME (SECONDS)
CDU INPUTS	MODE SWITCH AND LINE KEY ACTIVATION TIMES (SECONDS) ERROR COUNT
SENSOR FIELD OF REGARD	MEAN AZIMUTH AND ELEVATION DISTRIBUTION (5 DEGREE INTERVALS)
FIELD OF VIEW	PERCENT OF TIME NARROW AND WIDE PERCENT OF PILOT OR COPILOT CONTROL
PILOT WORKLOAD	CONTROL ACTIVITY (HIGH FREQUENCY) AIRCRAFT ANGULAR RATES
SWITCH ACTIVATIONS	ACTIVATION TIME (SECONDS)
NOTE: ALL MEASURES START 1 MINUTE INTO RUN AND END 1 NAUTICAL MILE FROM LANDING ZONE.	

6.1 Approach and Landing Symbology Evaluation

Data were gathered during the symbology evaluation primarily to determine the effects of symbology set and landing zone (LZ) difficulty on pilot performance. Analysis of various groups of data are discussed below.

6.1.1 Analysis of Variance - Touchdown Data (Symbology: Approach and Landing)

An analysis of variance (ANOVA) was conducted to determine the effect of the independent variables of symbology set and LZ difficulty level on pilot touchdown performance (Table 6-I). The dependent variables were landing time (in seconds), distance in feet from a predescribed touchdown point (radial landing error), longitudinal aircraft axis drift (X drift), lateral aircraft axis drift (Y drift), and vertical aircraft axis drift (Z drift) in feet per second. As shown in Table 6-III, no significant differences ($p \leq 0.10$) were found in the dependent variables as a function of symbology set with the exception of right lateral drift (+Y). The effects of LZ size on landing time and radial landing error were predictable (i.e., the smaller the LZ, the longer the landing time and the smaller the radial landing error). The hover symbology set had the smallest time spread and error differences between zone sizes.

Significant interaction effects were found between symbology set and difficulty level with landing time, positive X drift (forward), and Z drift. As shown in Table 6-IV, the window box large zone had the shortest landing time (126 seconds) followed by the hover meter large zone (130 seconds). Pilots using the flight symbology in the very small zone had the longest landing time (275 seconds), and the hover meter small zone the next to the longest time (263 seconds). The least amount of X drift was with the hover symbology in the large zone (0.005 ft/s). The largest amount of positive X drift appeared with the flight set small zone (3.2 ft/s). The rate of descent (Z drift) was lowest with the hover meter in the small zone (3.12 ft/s) followed by the window box in the medium sized zone (3.32 ft/s). The fastest descent rate was found in the window box (8.65 ft/s) in the very small zone and the flight symbology small zone (8.53 ft/s). The

TABLE 6-III

Pilot Performance In Symbology Evaluation: Touchdown*

DEPENDENT VARIABLES	OVERALL MEAN	STANDARD DEVIATION	INDEPENDENT VARIABLES: SYMBOLOGY SET	INDEPENDENT VARIABLES: DIFFICULTY LEVEL	INDEPENDENT VARIABLES: INTERACTION
LANDING TIME	174.985	77.3	NS**	p = 0.001	p = 0.008
RADIAL LANDING ERROR	40.57 FT	35.4	NS	p = 0.001	NS
–X DRIFT	–1.98 FT/S	2.66	NS	NS	NS
+X DRIFT	+2.10 FT/S	1.93	NS	NS	p = 0.049
–Y DRIFT	–1.38 FT/S	1.33	NS	NS	NS
+Y DRIFT	+1.20 FT/S	1.30	p = 0.10	NS	NS
Z DRIFT	–5.77 FT/S	3.24	NS	p = 0.078	p = 0.001

*SIGNIFICANCE LEVEL LIMITED TO $p \leq 0.10$
**DIFFERENCES NOT SIGNIFICANT

TABLE 6-IV

Significant Symbology Evaluation Touchdown Data

SYMBOLOGY SET	DEPENDENT VARIABLE BY LANDING ZONE SIZE																
	LANDING TIME (SECONDS)				LANDING ERROR (FEET)				+X DRIFT (FT/S)				Z DRIFT (FT/S)*				–Y DRIFT (FT/S)*
	LARGE	MEDIUM	SMALL	VERY SMALL	LARGE	MEDIUM	SMALL	VERY SMALL	LARGE	MEDIUM	SMALL	VERY SMALL	LARGE	MEDIUM	SMALL	VERY SMALL	ALL ZONES
FLIGHT	141	135	158	275	88.6	50.5	25.5	38.9	2.4	0.58	3.2	1.1	5.3	6.1	8.5	6.1	1.10
HOVER	177	158	148	188	58.8	53.7	29.4	22.7	0.065	0.50	1.9	2.7	3.7	5.8	6.2	5.0	0.89
WINDOW BOX	126	168	263	289	63.2	48.9	66.9	23.4	2.6	0.58	1.3	2.6	8.5	3.3	3.8	8.7	1.2
HOVER METER	138	170	175	186	52.38	78.6	69.2	26.8	3.6	0.46	2.4	1.4	5.3	3.4	3.1	7.4	1.2

*Y DRIFT RESULTED IN NO SIGNIFICANT EFFECTS DUE TO LANDING ZONE SIZE

radial landing error was the smallest when using the hover symbology in the smallest LZ (22.7 feet), and the largest with the hover meter in the medium sized LZ (70.6 feet). Negative Y drift (leftward) was not affected by LZ size and was the smallest with the hover symbology set (0.89 ft/s). Generally, difficulty of the LZ size affects pilot performance at touchdown more than the hover symbology set. The smaller the LZ, the more workload requirement on the pilot to land safely. The test conductor (acting as simulated crew chief), available on call by the pilots, helped direct them into the LZ thereby reducing pilot reliance on symbology.

Although no symbology set consistently exhibited the best performance on all measures, certain patterns are discernible. Table 6-V contains the relative performance ranking between symbology sets. The hover symbology set had the shortest landing time across LZ sizes, the lowest X drift across LZ sizes, the smallest landing error, the lowest rate of descent (Z drift), and the smallest Y drift. In the overall rankings, the hover symbology ranked number one in performance and the window box second. Hover symbology ranked highest because it provides the pilot with more information with which to control aircraft horizontal position in a hover. Flight symbology ranked third in performance because the pilot had only Doppler speed and the display imagery to indicate the drift rate.

In summary, the hover symbology had the best landing performance overall, followed by the window box symbology.

6.1.2 Smoothness of Approach and Landing (Symbology: Approach and Landing)

During each approach and landing data run, aircraft performance variables were recorded every other second during the 60 seconds prior to touchdown as well as every 0.1 nmi within 1.0 nmi of touchdown. To assess the pilot's visual interpretation of the different graphical presentations of hover symbology sets and his ability to transfer this interpretation to controlling the aircraft during the approach and landing phase, time and distance distributions for smoothness of approach and touchdown were projected. The performance variables in these distributions were: radar altitude, rate of descent, groundspeed, pitch angle, and collective application in percent torque. These distributions are defined under aircraft status in Table 6-I. A second order polynomial was fitted to the data because a perfectly smooth approach and landing would follow a second order polynomial curve. The residual mean square for the second degree polynomial was used as an indication of diffences in smoothness between actual and ideal approaches as indicated by the experimental variables. In a second order polynomial equation, the independent variable is raised to the second power. This second order indicates that there is a single bend in the regression curve. We would not expect the pilots to fly straight into the LZ due to the terrain obstacles. The ideal flight path is a smooth approach with one bend to get over the trees that are around the LZ. Analysis of variance was performed on the distributions to examine any differences in approach smoothness or consistency. The probability limit for significance was $p \leq 0.10$.

Significant differences in smoothness of approach were found in two distributions. First, the flight symbology (no hover set) had the most consistent pitch angle in the distance distribution during approach.

TABLE 6–V

Symbology Evaluation Relative Rankings of Touchdown Data

SYMBOLOGY SET	LANDING TIME					LANDING ERROR					+X DRIFT					Z DR:					–Y DRIFT	OVERALL RANK
	LARGE	MEDIUM	SMALL	VERY SMALL	MEAN	LARGE	MEDIUM	SMALL	VERY SMALL	MEAN	LARGE	MEDIUM	SMALL	VERY SMALL	MEAN	LARGE	MEDIUM	SMALL	VERY SMALL	MEAN	ALL ZONES	
FLIGHT	3	1	2	4	2	4	2	1	4	3	2	4	4	1	4	25	4	4	2	4	4	4*
HOVER	4	2	1	1	1	2	3	2	1	1	1	2	2	4	1	1	3	3	1	1	1	1
WINDOW BOX	1	3	4	3	35	3	1	3	2	2	3	3	1	3	25	4	1	2	4	3	25	2
HOVER METER	2	4	3	2	35	1	4	4	3	4	4	1	3	2	25	25	2	1	3	2	25	3

*1 – BEST RANKING

Figure 6-1 indicates the pitch angle of the four symbology sets from 1.0 nmi to touchdown. The LZ sizes did not significantly affect pitch angle and were combined across symbology sets. The hover symbology had the next smoothest pitch angle followed by the hover meter and the window box respectively. Second, the LZ difficulty affected the radar altitude as a function of the distance distribution. The radar altitude approach glide path was more stable for the small LZs than for the larger zones (Figure 6-2). Pilots were required to have their altitude and airspeed under control to safely enter the small zones. The symbology sets did not significantly affect the radar altitude and were combined across LZs. Additional approach trends, although not statistically significant, show the hover meter to have the smoothest approach with respect to descent rate, speed, and percent torque. Groundspeed trends are shown in Figure 6-3. The setdown results showed the smoothest pitch angle, speed, and radar altitude to be with the window box. Additionally, the hover symbology set showed a smooth descent rate. The inconsistent symbology trends in aircraft altitude during the last few seconds (time distribution) and nautical mile (distance distribution) before touchdown indicate that the various hover symbology sets have little effect on smoothness of approach. This might be explained by the information common to all symbology sets (i.e., groundspeed, rate of descent, radar altitude, and torque) giving necessary landing data, as well as the simulated crew chief available on call by the pilot for additional landing information.

6.1.3 Crash Rates (Symbology: Approach and Landing)

Chi-square analysis was performed on the number of noncrash landings based on total attempts to land. This analysis showed no significant frequency differences as a function of symbology set or difficulty level.

There were very few landings that would not be classified as poor or technical crashes by the criterion established in the test plan and shown in Table 6-VI. The rate of descent was the most frequent cause for poor landings across all experimental conditions followed by pitch angle and rearward drift respectively. The most frequent cause of technical crashes exceeding the established criterion was pitch angle followed by rate of descent. There were very few poor landings or crashes caused by left and right roll or forward drift. No landings exceeded the criteria for side drift (Y). The frequencies and types of poor landings and crashes were fairly evenly dispersed across all treatment conditions.

6.1.4 Discrete Activities (Symbology: Approach and Landing)

6.1.4.1 Percent Time Narrow Field of View Commanded

Only the pilot in command (the pilot at the controls) made the FOV commands for this group of subjects. There were no FOV commands in the approach phase and very few in the landing and takeoff phases. There was minimal variability in percentages of time in the narrow FOV as a function of LZ size and virtually no variability due to symbology set. This was predictable since all of the hover symbology sets are only used during

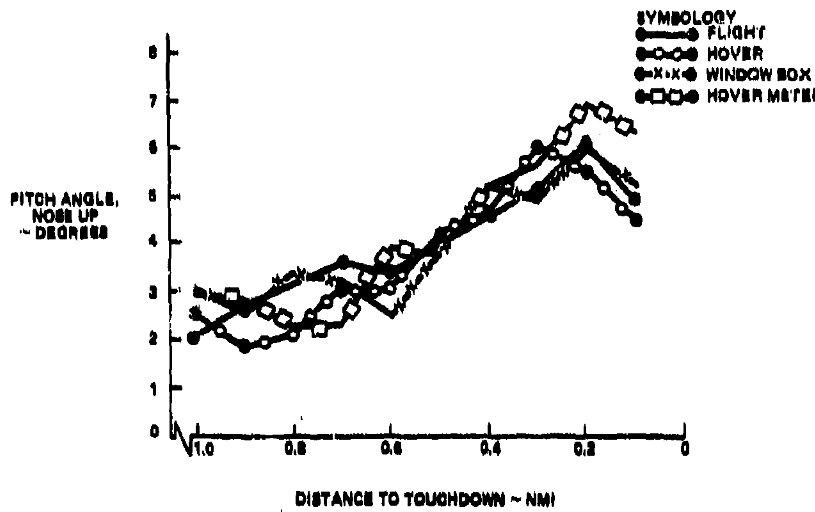

Figure 6-1. Pitch Angle during Landing Phase

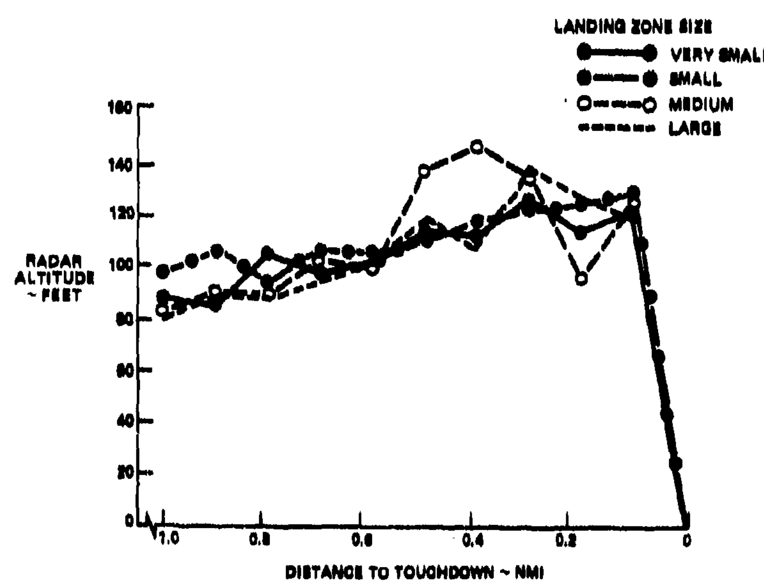

Figure 6-2. Radar Altitude during Landing Phase

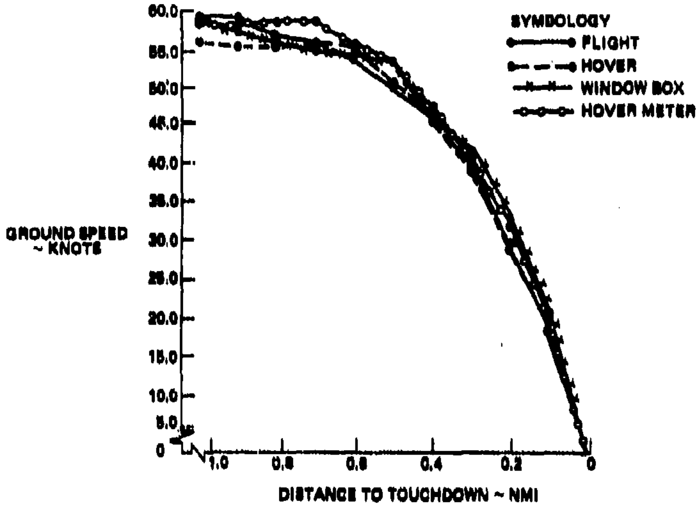

Figure 6-3. Groundspeed during Landing Phase

TABLE 6-VI

Criterion Values for Poor Landings and Crashes

PLANE	CRASH GREATER THAN	POOR LANDING GREATER THAN
VERTICAL, Z (FT/S)	10.33	3.33
SIDEWAYS, Y (FT/S)	+ -15	+ -10
FORWARD, X (KNOTS)	10	5
REARWARD, X (KNOTS)	-5	-2
ROLL RIGHT (DEGREES)	10	3
ROLL LEFT (DEGREES)	10	5
PITCH, NOSE UP (DEGREES)	15	10

NOTE: CRITERION VALUES PROVIDED BY NATC TEST PILOTS DURING PHASE I STUDY

landing. In the landing phase, the largest percentage of time spent in narrow FOV was 0.41 percent in the large size LZ, and the least amount of time was 0.089 percent in the medium size landing zone.

6.1.4.2 Sensor Actuations per Run

Sensor slewing was shared by pilot and copilot. As shown in Figure 6-4, there was a large variability in sensor usage between experimental conditions and between pilot in command and copilot. Overall, the copilot slews the sensor more than the pilot especially in the small and very small LZs. The pilot and copilot frequency differences were less pronounced in the large and medium zones. One explanation of this difference would be the necessity for increased pilot attention to flying the aircraft when landing in the smaller zones. The trend of more sensor slewing in the smaller zones would indicate a need to examine the small landing area for obstacles with the copilot in control of the sensor, thereby freeing the pilot in command for the actual landing requirements. The frequency of sensor slewing is important since the data runs were of relatively short duration (approximately 3 miles long). The crews used the gimballed sensor during these short flights proportionally more often than observed during the longer enroute data runs of previous simulations (Reference 5).

6.1.4.3 Sensor Azimuth and Elevation

Sensor azimuth and elevation data during the approach portion of the symbology evaluation data runs indicated little difference due to experimental conditions. This was expected since the flight symbology was used during the entire approach portion of the mission. During the transition and landing portions of the data runs, the differences were small as a function of experimental condition.

Figures 6-5 through 6-8 display the percent of time spent at each azimuth gimbal angle for the experimental conditions of symbology formats and LZ size. The sensor was not slewed more than 30 degrees to the left or 45 degrees to the right, and remained centered 99 percent of the time. The spurious peaks at several azimuth angles were not consistent by LZ size or symbology set and are probably due to chance. The very small zone resulted in the most variability in elevation (Figure 6-9). The sensor remained centered in elevation the least amount of time with the flight symbology (64 percent) followed by the hover (79 percent), hover meter (83 percent), and window box (89 percent). The sensor was never slewed up and was slewed the farthest down with the hover meter (50 degrees down). Aside from the small LZ, the remaining LZ sizes show very little sensor slewing in elevation (Figures 6-10 through 6-12).

6.2 Approach and Landing FOV Evaluation

Data were gathered during the FOV evaluation primarily to determine the effects of FOV and LZ difficulty on pilot performance (Table 6-I). After two pilot groups (eight pilots) had completed the FOV evaluation, a

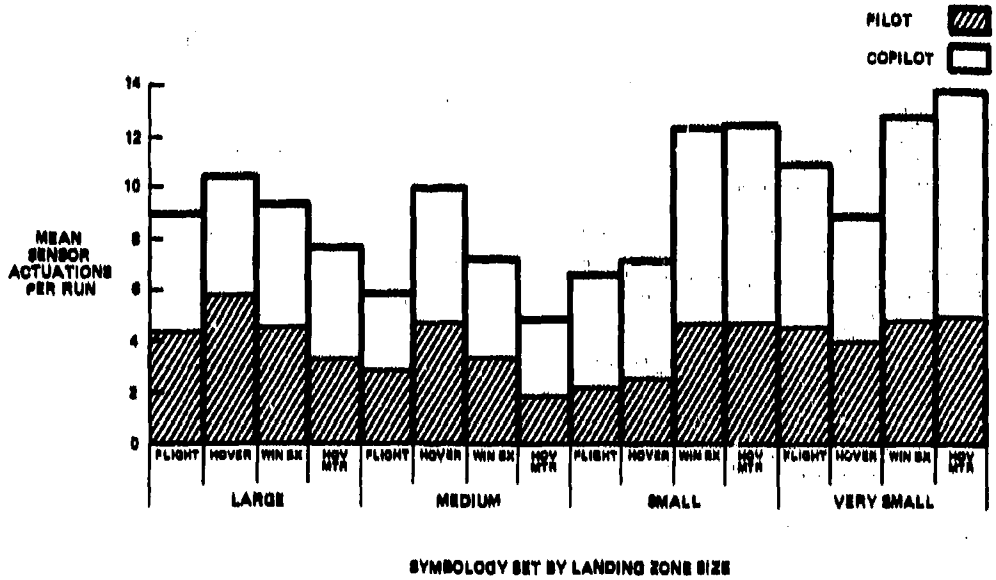

Figure 6-4. Mean Sensor Actuations Per Run

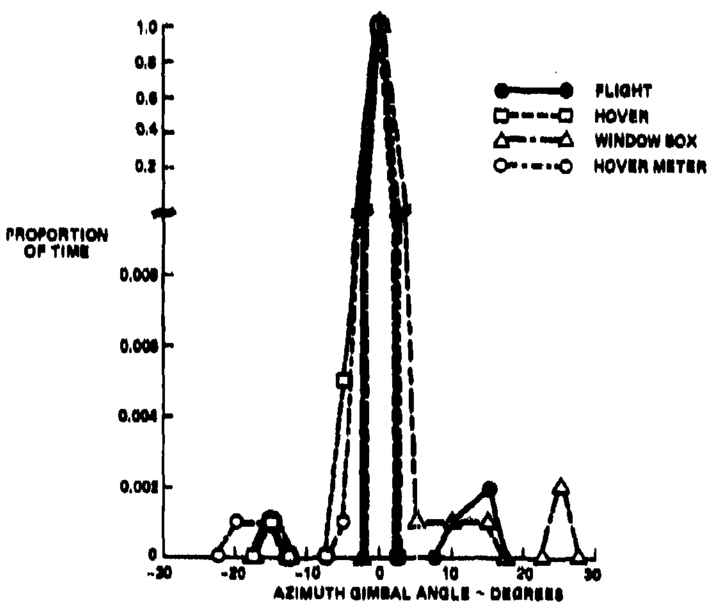

Figure 6-5. Sensor Azimuth Gimbal Angle Distribution: Very Small LZ

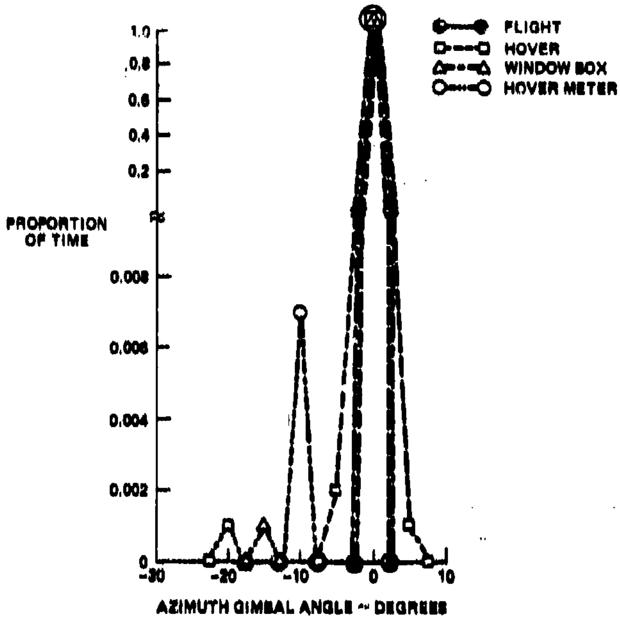

Figure 6-6. Sensor Azimuth Gimbal Angle Distribution: Small LZ

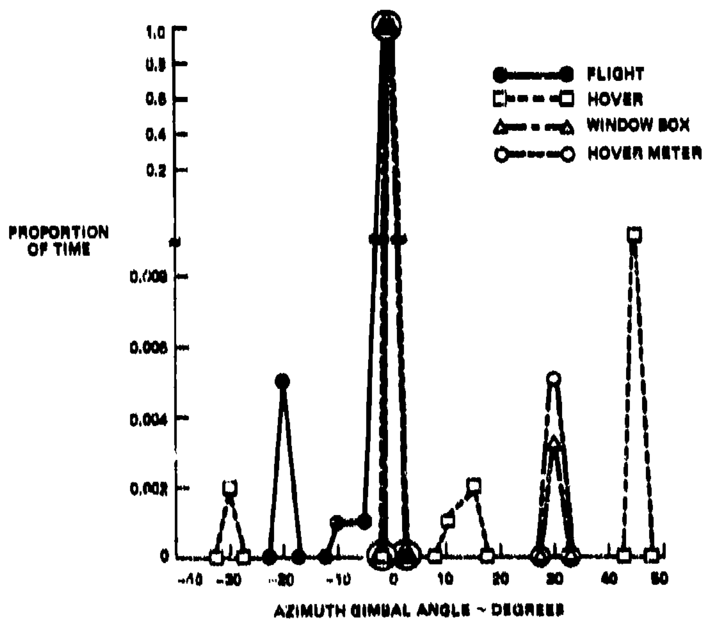

Figure 6-7. Sensor Azimuth Gimbal Angle Distribution: Medium LZ

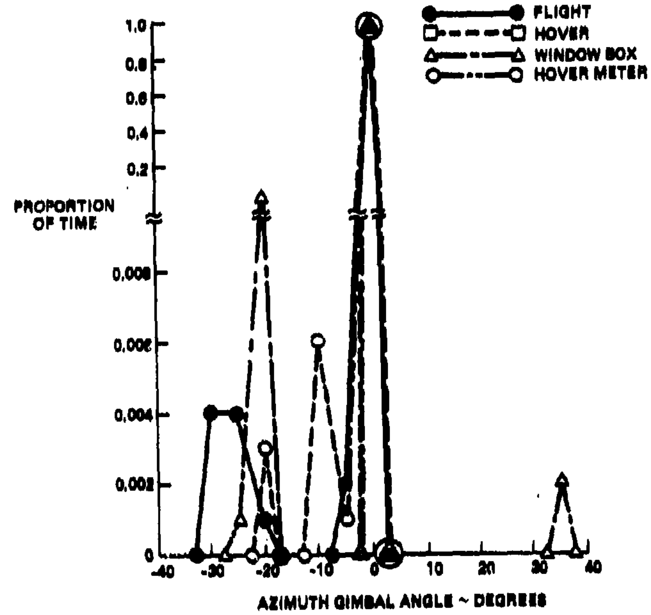

Figure 6-8. Sensor Azimuth Gimbal Angle Distribution: Large LZ

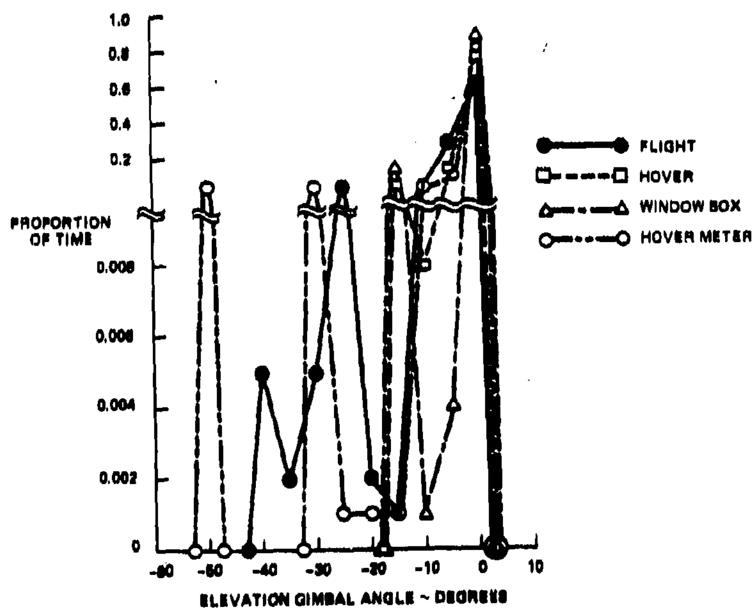

Figure 6-9. Sensor Elevation Gimbal Angle Distribution: Very Small LZ

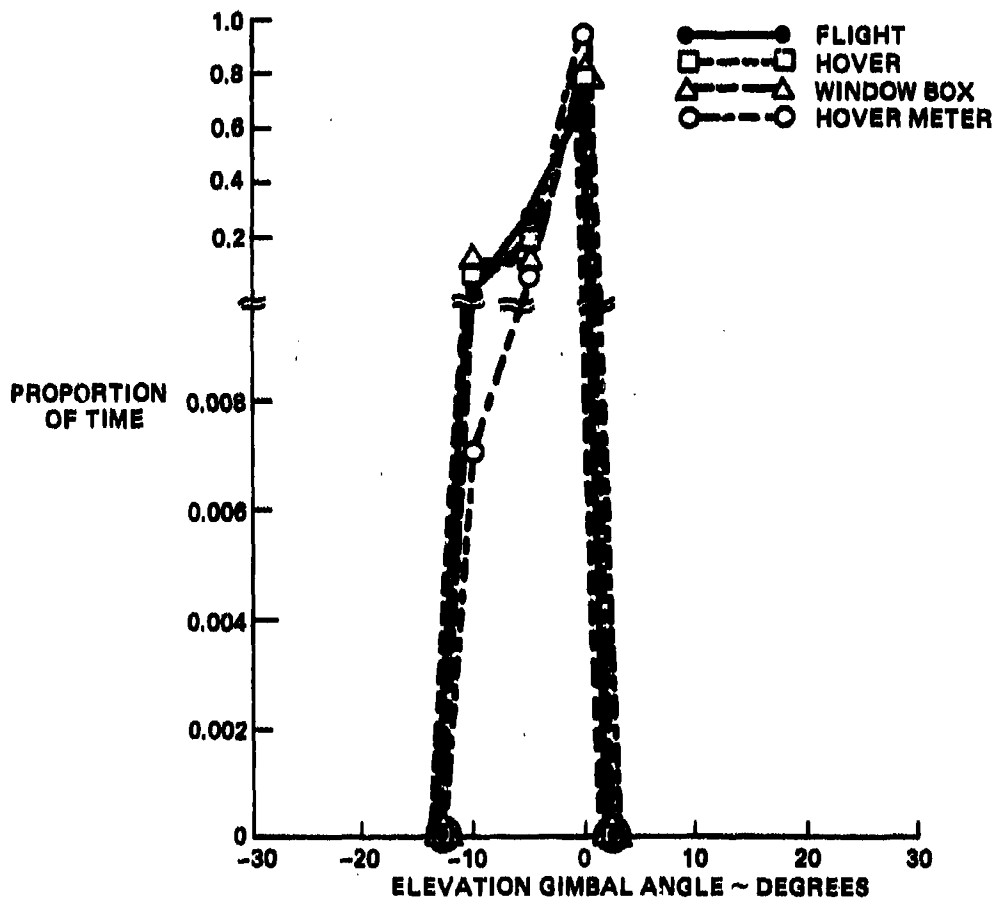

Figure 6-10. Sensor Elevation Gimbal Angle Distribution: Small LZ

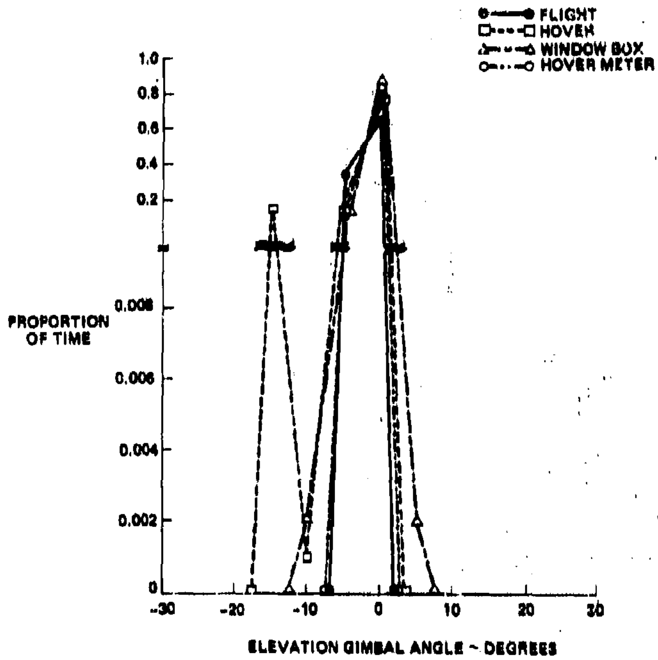

Figure 6-11. Sensor Elevation Gimbal Angle Distribution: Medium LZ

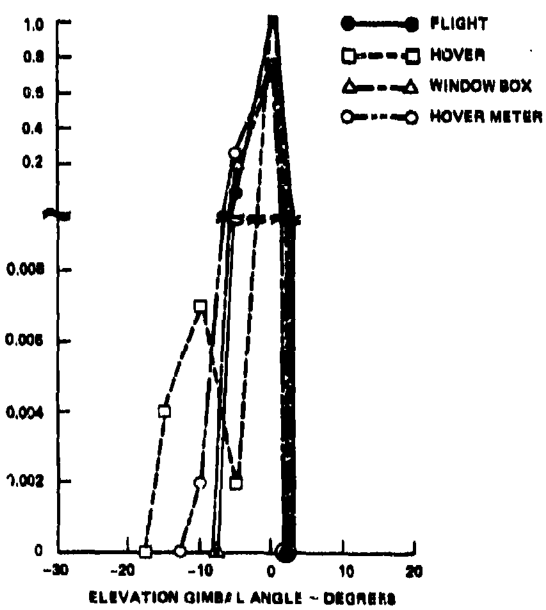

Figure 6-12. Sensor Elevation Gimbal Angle Distribution: Large LZ

program review was held to discuss the FOV preliminary data results. The consensus reached at that program review was that the data generated by these two pilot groups were sufficient to evaluate FOV effects on pilot performance and that the remaining pilot group event would be rescheduled for incorporating the Honeywell IHADSS hardware into the cockpit for the copilot virtual HUD evaluation. Therefore, the data discussed for the FOV evaluation is based on eight pilots rather than the standard three pilot groups of four pilots for a total of twelve used throughout the rest of this simulation experiment.

6.2.1 Touchdown and Enroute Data (FOV: Approach and Landing)

Touchdown performance was analyzed on five dependent variables: landing time, radial landing error, X drift, Y drift, and Z drift during landing; and three approach variables: average altitude, average groundspeed, and percent of time under 100 feet during the approach portion of the data run. The independent variables were FOV and LZ difficulty. Table 6-VII shows no significant touchdown performance effects due to FOV or LZ size. Although not significantly different, wide and dual FOVs tend to result in better performance, on most variables, than did the narrow FOV. There is a significant interaction effect between FOV and LZ difficulty level with reference to rate of descent (Z drift). Wide FOV, in the large zone resulted in the smallest drift followed by wide FOV in the medium zone. Tables 6-VIII and 6-IX show that the wide FOV resulted in the smallest rate of descent, followed by the dual FOV.

6.2.2 Smoothness of Approach and Landing (FOV: Approach and Landing)

Regression analyses were run on time and distance distributions of performance variables as in section 6.1.2. The differences in residuals for radar altitude over distance were significant by LZ size and FOV configuration. Figure 6-13 shows the average radar altitude in the terminal landing phase for wide, narrow, and dual FOV (across all zone sizes). This figure shows that altitude control using the wide FOV is less variable when compared to a more erratic approach profile using the narrow FOV. Regardless of the FOV configuration, the pilots tend to approach well above the trees (average 80 foot tree height) and let down vertically. The radar altitude for LZ approach was significantly smoother in wide FOV than in narrow. The approach radar altitude for the two small LZs combined was significantly smoother than for the two larger LZs combined (Figure 6-14). This would indicate a more controlled altitude approach for the difficult landing zones than for the easier zones. There were no significant interaction effects between LZ size and FOV.

The vertical rate of descent across distance was significantly smoother for the smaller two LZs than for the larger two. This again indicated the necessity for a smooth approach into the smaller zones. Figure 6-15 indicates a rapid descent rate at 0.5 nmi in the small landing and then a climb to clear the trees. Approach into larger zones had an erratic

TABLE 6-VII

Pilot Performance in FOV Evaluation: Touchdown and Approach*

DEPENDENT VARIABLES	OVERALL MEAN	STANDARD DEVIATION	INDEPENDENT VARIABLES		
			FIELD OF VIEW	DIFFICULTY LEVEL	INTERACTION
TOUCHDOWN					
LANDING TIME	187.74S	62.71	NS**	NS	NS
RADIAL LANDING ERROR	34.46 FT	27.81	NS	NS	NS
-X DRIFT	-1.93 FT/S	1.91	NS	NS	NS
+X DRIFT	+1.92 FT/S	1.73	NS	NS	NS
-Y DRIFT	-1.31 FT/S	1.36	NS	NS	NS
+Y DRIFT	+0.83 FT/S	1.01	NS	NS	NS
Z DRIFT	-2.789 FT/S	1.72	NS	NS	p = 0.018
APPROACH				LANDING ZONE DOES NOT AFFECT APPROACH VARIABLES	
PERCENT UNDER 100 FEET	43.51 %	9.10	NS		
AVERAGE GROUNDSPEED	58.29 KN	3.35	NS		
AVERAGE ALTITUDE	111.82 FT	10.40	NS		

*SIGNIFICANCE LEVEL LIMITED TO $p \leq 0.10$
**DIFFERENCE NOT SIGNIFICANT

TABLE 6-VIII

Significant FOV Evaluation
Touchdown Data

FIELD OF VIEW	Z DRIFT BY LANDING ZONE SIZE			
	LARGE	MEDIUM	SMALL	VERY SMALL
WIDE	1.81	1.97	3.02	2.89
NARROW	3.10	2.32	2.08	4.11
DUAL	2.23	4.19	2.98	2.81

TABLE 6-IX

Relative Rankings of Significant
FOV Touchdown Data

FIELD OF VIEW	LANDING ZONE SIZE				
	LARGE	MEDIUM	SMALL	VERY SMALL	OVERALL RANK
WIDE	1	1	3	2	1*
NARROW	3	2	1	3	3
DUAL	2	3	2	1	2

*1 = BEST RANKING

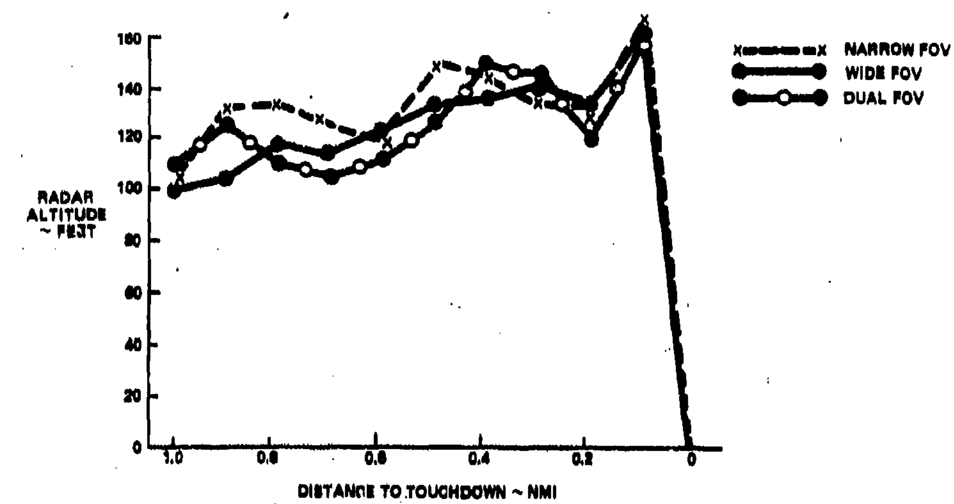

Figure 6-13. Radar Altitude during Landing Phase by FOV Only

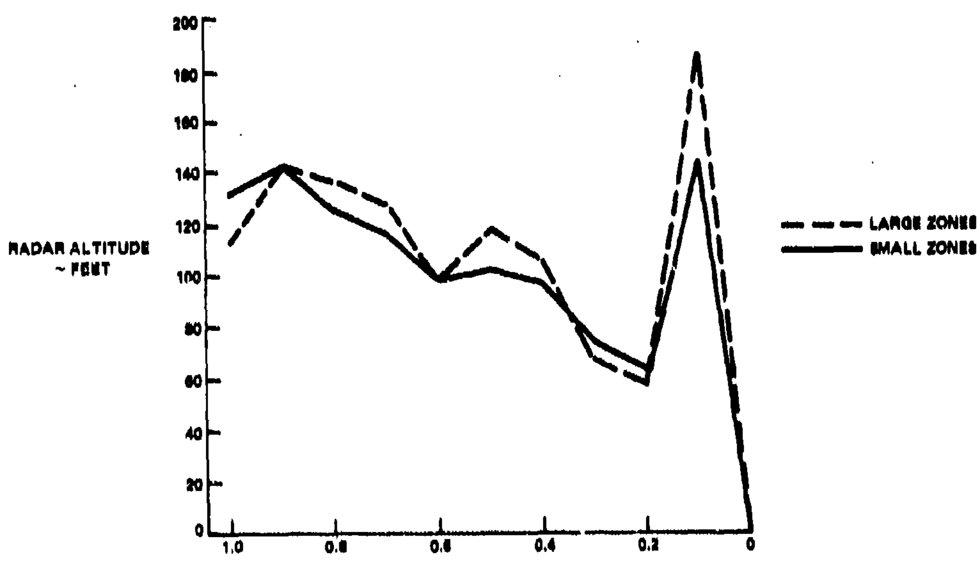

Figure 6-14. Radar Altitude during Landing Phase by LZ Only

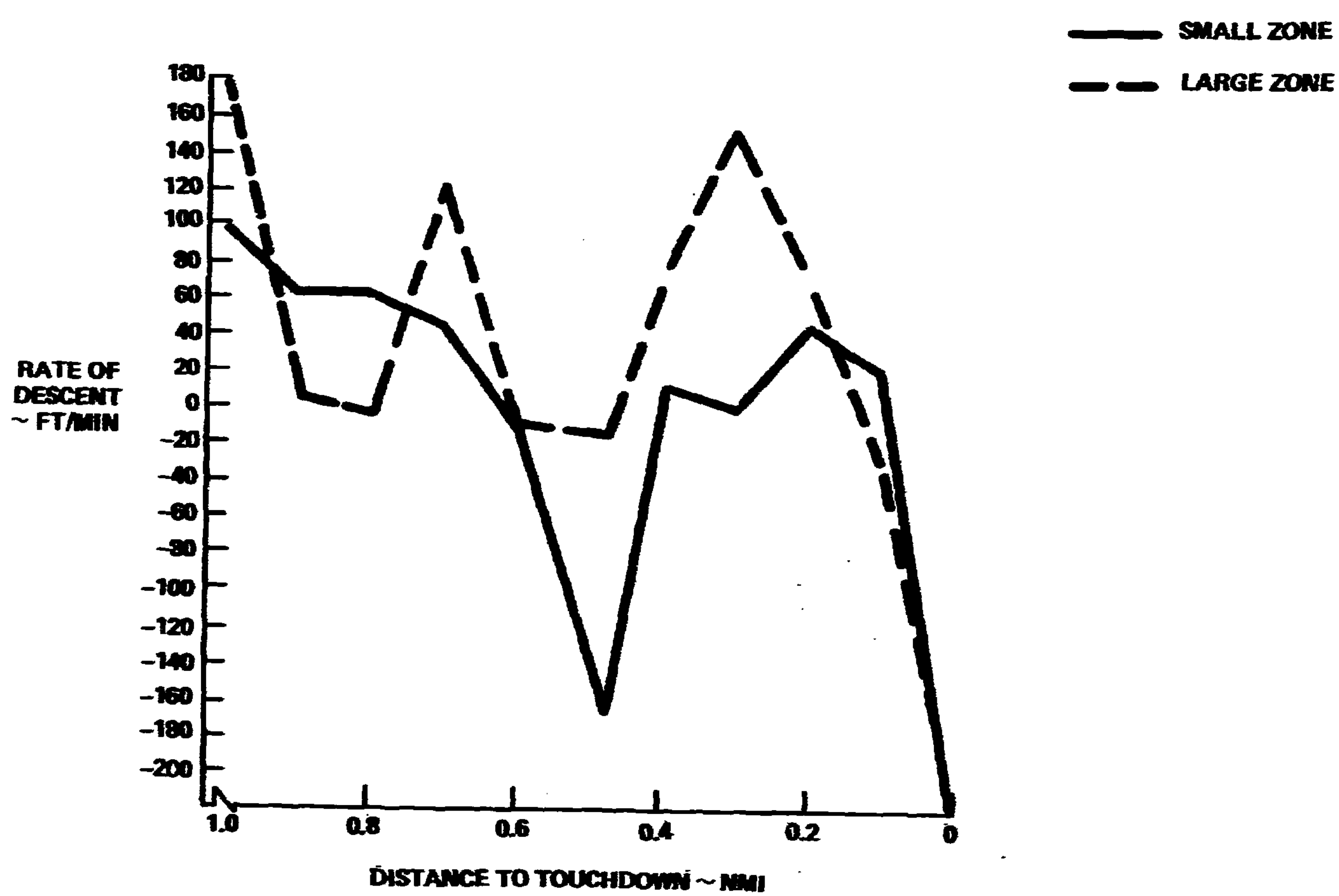

Figure 6-15. Rate of Descent during Landing Phase by LZ Only

descent rate. Rate of decent was not affected by FOV. Collective application as indicated by the variation in torque across time was also significantly more stable for small zones than for larger zones (Figure 6-16). Nonsignificant trends in the approach distributions indicate an inconsistent speed for narrow FOV. This is perhaps due to misjudgement of aircraft distance to the zones when in narrow FOV. Generally, the distribution again indicates that difficulty level affects performance more than FOV.

6.2.3 Crash Rates (FOV: Approach and Landing)

Chi-square analysis of the number of total attempts resulting in landings showed that the frequency differences were probably not due to chance ($p = 0.0035$), i.e., difficulty level combined with FOV affects the rate of successful landing attempts (Table 6-X). The narrow FOV had the smallest percentage of landings per attempts (46 percent) in the medium LZ. The highest landing rate per attempts (100 percent) was with the wide FOV in very small LZs. Examination of FOV and difficulty level independently did not result in significant differences.

The technical poor landings were due to pitch angle, rate of descent, and rearward drift with equal frequencies. The narrow FOV had the most poor landings followed by dual and wide respectively. However, the differences in frequencies were not statistically significant (Table 6-XI). There were no technical crashes in the FOV evaluation.

6.2.4 Discrete Activities (FOV: Approach and Landing)

6.2.4.1 Percent Time Narrow FOV Commanded

The pilot at the controls of the aircraft in the FOV evaluation made the majority of FOV selections. Table 6-XII shows the percentage of time spent in narrow FOV by the flight phase and LZ difficulty level. The pilots were briefed before each data run set and encouraged to use their dual FOV capability. However, the largest amount of time spent in the narrow FOV by the pilot was only 2.09 percent during approach to the smallest LZ. The amount of time in narrow FOV decreased markedly during landing and takeoff. Without continued encouragement, the pilots tended to not use the narrow FOV. The pilots apparently felt the wide FOV presented sufficient visual feedback to accomplish the approach, landing, and takeoff phases of the mission.

6.2.4.2 Sensor Actuations per Run

Figure 6-17 indicates a large variability in the number of sensor actuations per data run. Sensor slewing was shared by the pilot and copilot; however, the copilot slews the sensor more often than the pilot at the controls of the aircraft and more frequently in the smaller LZs, reinforcing the need for a center console sensor control capability. The largest frequency of sensor actuations occured in the very small zone in narrow FOV. This would indicate a necessity to look around to overcome the

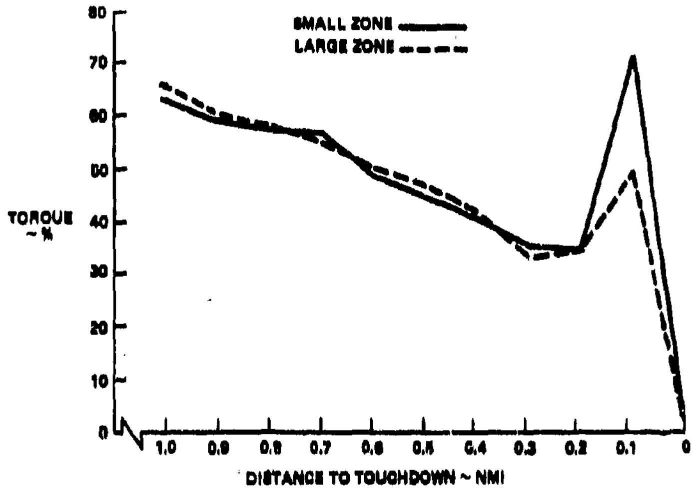

Figure 6-16. Percentage of Torque Applied during Landing Phase by LZ Only

TABLE 6-X

Field of View Evaluation: Percentage of Total Data Route Attempts That Resulted in Completed Runs and Landing

FIELD OF VIEW	LANDING ZONE SIZE			
	LARGE	MEDIUM	SMALL	VERY SMALL
WIDE	73	70	67	100
NARROW	78	46	50	73
DUAL	80	75	64	80

TABLE 6-XI

Field of View Evaluation: Technical Poor Landings

FIELD OF VIEW	LANDING ZONE SIZE AND NUMBER OF ERRORS BY TYPE				
	LARGE	MEDIUM	SMALL	VERY SMALL	TOTAL
WIDE	1 (-X DRIFT) 1 (Z DRIFT)	2 (-X DRIFT) 1 (Z DRIFT) 1 (PITCH)	1 (+X DRIFT) 4 (Z DRIFT) 2 (PITCH)	1 (-X DRIFT) 2 (Z DRIFT) 1 (PITCH)	17
NARROW	1 (-X DRIFT) 4 (Z DRIFT) 2 (PITCH) 1 (ROLL RIGHT)	1 (-X DRIFT) 1 (+X DRIFT) 1 (Z DRIFT) 2 (PITCH)	1 (Z DRIFT)	2 (-X DRIFT) 5 (Z DRIFT) 2 (PITCH)	23
DUAL	1 (-X DRIFT) 1 (Z DRIFT) 1 (PITCH)	3 (-X DRIFT) 3 (Z DRIFT) 1 (PITCH) 1 (ROLL RIGHT)	1 (-X DRIFT) 2 (Z DRIFT) 1 (ROLL LEFT)	2 (-X DRIFT) 2 (Z DRIFT) 1 (PITCH)	20

TABLE 6-XII

Percentage of Time in Narrow FOV

FLIGHT PHASE	LANDING ZONE SIZE	PERCENT OF TIME IN NARROW FOV	
		PILOT	COPILOT
APPROACH	VERY SMALL	2.09	0
	SMALL	1.10	1.459
	MEDIUM	1.28	0
	LARGE	0.735	1.042
LANDING	VERY SMALL	0.197	0
	SMALL	0.135	0
	MEDIUM	0.621	0
	LARGE	0.616	0.179
TAKEOFF	VERY SMALL	0	0
	SMALL	0.893	1.618
	MEDIUM	0	0
	LARGE	0.368	0

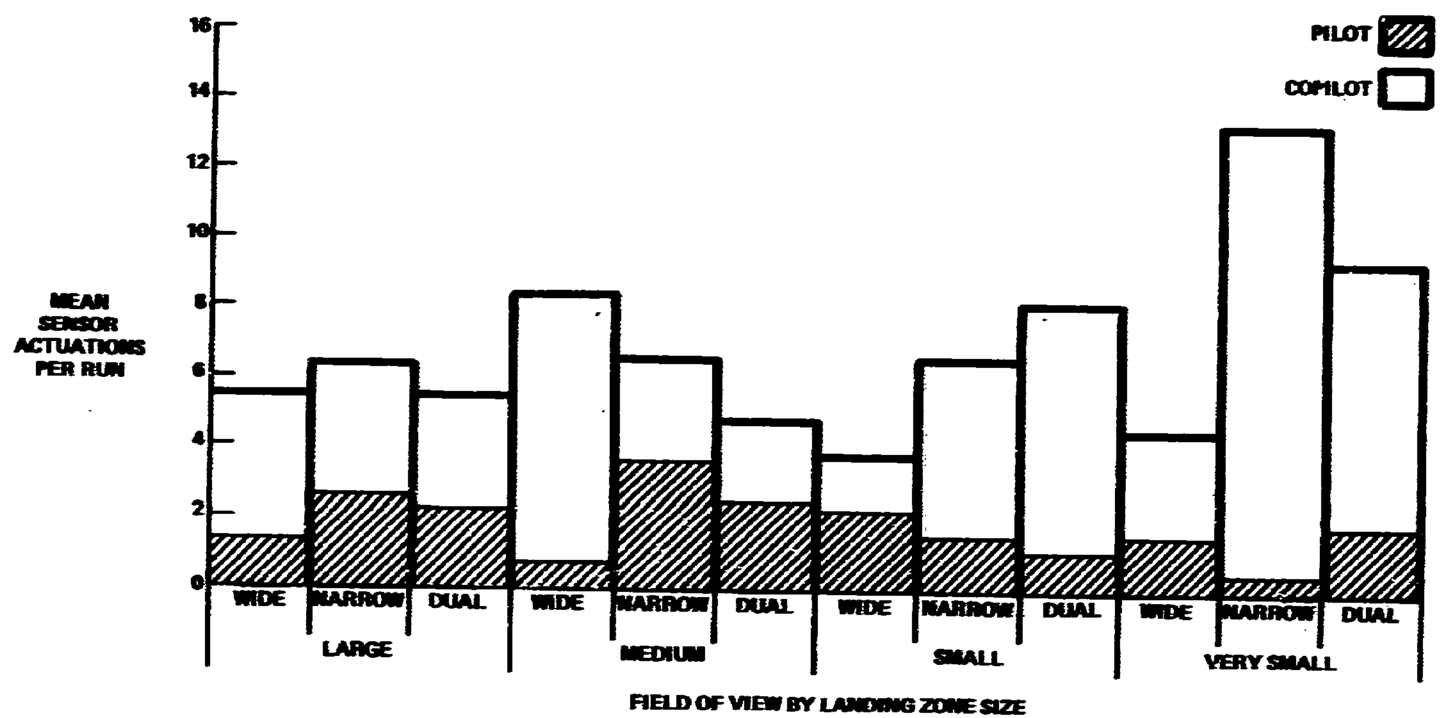

Figure 6-17. Mean Number of Sensor Actuations per Run

reduced imagery size of the narrow FOV. For small zones, the wide FOV required the least number of sensor actuations. The mean data shown here includes all phases of the flight, but the approach phase taken separately is consistent (i.e., generally more sensor actuations per run for the forced narrow FOV). The mean distance to the next checkpoint at which sensor slewing occured was 0.32 nmi and was not affected by experimental condition (Table 6-XIII). Since the average distance between checkpoints was approximately 0.75 nmi, a mean sensor slewing distance of 0.32 nmi indicates that pilots slewed the sensor throughout each leg for terrain avoidance as opposed to looking for checkpoints at the end of legs. Overall, the pilot groups used the gimballed sensor proportionally more often than observed during the longer enroute data runs of previous situations (Reference 5).

6.2.4.3 Sensor Azimuth and Elevation

During the approach (1.5 to 0.6 nmi from touchdown) and takeoff (touchdown to 1.0 nmi out) phases, the sensor remained centered 90 percent of the time and remained within 25 degrees of center all of the time. The narrow FOV had slightly more sensor actuations than dual and wide. Figures 6-18 and 6-19 show the azimuth and elevation gimbal angles for the landing phase. The crews used a larger field of regard range in the narrow FOV, presumably to compensate for the reduced FOV. In all FOVs, the sensor was never slewed up and was slewed down when entering the LZ to compensate for the high aircraft nose up attitude during deceleration.

The landing phase required more slewing of the sensor. During landing, the sensor remained centered 90 percent of the time and within 60 degrees of center all of the time in azimuth. In elevation, the sensor remained level 50 to 65 percent of the time, was never slewed up, and was slewed down 60 degrees less than 0.01 percent of the time.

6.3 Approach and Landing PMD-HMD Evaluation

During the third study, crew performance data were gathered with the pilot and copilot using three combinations of the HMD and PMD. The combinations under study were: pilot and copilot using a PMD; pilot using an HMD and copilot using a PMD; pilot and copilot using a HMD. Analysis of performance data appear below.

6.3.1 Touchdown and Enroute Data

The touchdown performance data were analysed on five dependent variables (landing time, radial landing error, X drift, Y drift, and Z drift) and three approach variables (percent under 100 feet, average altitude, and average groundspeed). The independent variables were three display configurations: PMD-PMD, PMD-HMD, and HMD-HMD. Table 6-XIV shows the levels of significance resulting from this analysis. The significant difference in landing error was expected as a function of zone size. Although no display combinations resulted in significant performance differences, trends

TABLE 6-XIII

Field of View Evaluation: Sensor Slewing Distance to the Next Checkpoint

FIELD OF VIEW	LANDING ZONE SIZE				MEAN
	LARGE	MEDIUM	SMALL	VERY SMALL	
WIDE	0.22	0.22	0.44	0.29	0.29
NARROW	0.28	0.47	0.25	0.19	0.30
DUAL	0.43	0.48	0.24	0.31	0.37

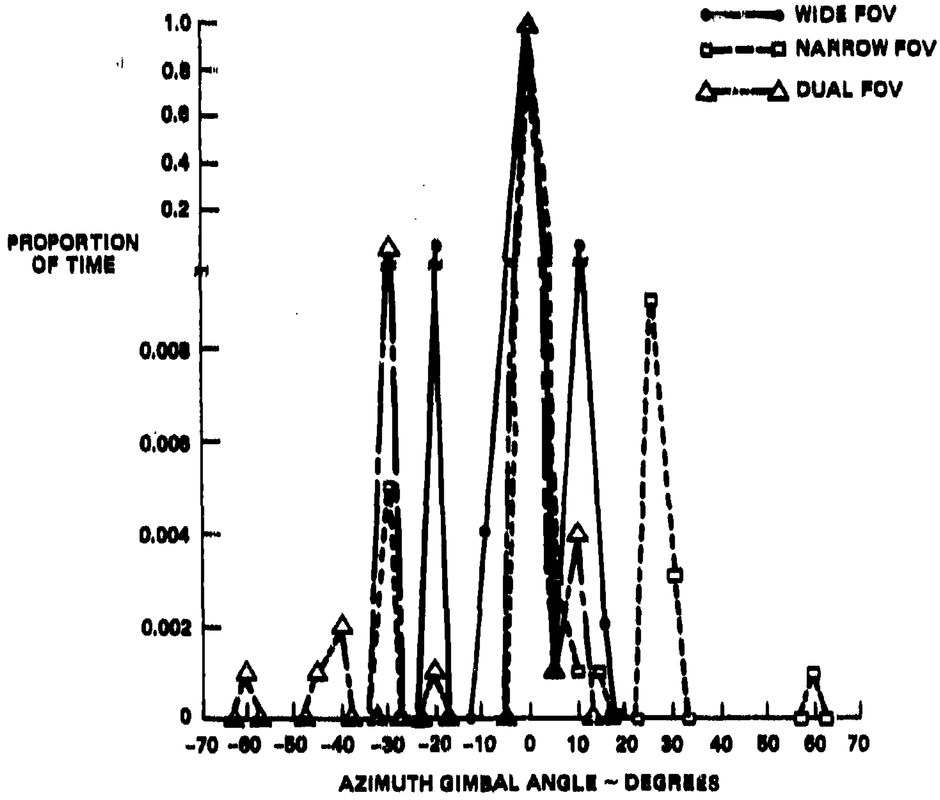

Figure 6-18. Sensor Azimuth Gimbal Angle Distributions by FOV

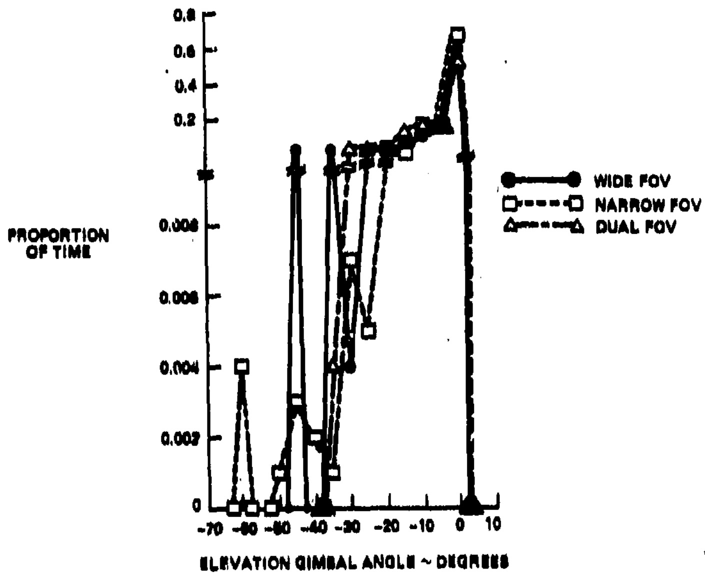

Figure 6-19. Sensor Evaluation Gimbal Angle Distributions by FOV

TABLE 6-XIV

Pilot Performance in HMD-PMD Evaluation: Touchdown and Approach

DEPENDENT VARIABLES	OVERALL MEAN	STANDARD DEVIATION	INDEPENDENT VARIABLES: DISPLAY CONFIGURATION	INDEPENDENT VARIABLES: DIFFICULTY LEVEL	INDEPENDENT VARIABLES: INTERACTION
TOUCHDOWN:					
LANDING TIME	234.528	100.70	NS**	NS	NS
RADIAL LANDING ERROR	31.67 FT	34.41	NS	p = 0.046	NS
-X DRIFT	-1.61 FT/S	1.68	NS	NS	NS
+X DRIFT	2.41 FT/S	3.16	NS	NS	NS
-Y DRIFT	-1.86 FT/S	1.60	NS	NS	NS
+Y DRIFT	1.24 FT/S	1.29	NS	NS	NS
Z DRIFT	4.48 FT/S	2.80	NS	NS	NS
APPROACH:					
PERCENT UNDER 100 FEET	36.66 %	26.81	NS	LANDING ZONE DOES NOT AFFECT APPROACH VARIABLES	
AVERAGE GROUNDSPEED	66.57 KN	12.36	NS		
AVERAGE ALTITUDE	119.04 FT	66.79	NS		

in favor of the HMD combinations do appear. HMD-PMD had the greatest time under 100 feet, the lowest mean radar altitude, the only mean altitude under 100 feet, and the least amount of Z drift. Tables 6-XV through 6-XVIII show the touchdown and approach results and relative rankings of these results between display configurations. The HMD-HMD combination had the shortest landing time and the best overall ranking on touchdown performance. These results indicate that it is the pilot's display that affects performance, and the performance is better with the HMD.

6.3.2 Smoothness of Approach and Landing (HMD/PMD: Approach and Landing)

Regression analyses were run on the distributions as detailed in section 6.1.2. The radar altitude for the last nautical mile before touchdown was significantly ($p = 0.10$) smoother for the HMD-PMD configuration than for PMD-PMD. Figure 6-20 shows the radar altitudes approaching the LZ as lower and smoother for the HMD-PMD configuration. Significant differences in distance distributions were also found in pitch angle. The pitch angle for the HMD-HMD was significantly ($p = 0.0028$) smoother than PMD-PMD, and difficulty level 1 (small LZ) was significantly smoother than level 2 (large LZ). This is shown in Figures 6-21 and 6-22. Examination of the time distribution indicated the rate of descent to be more consistent for the larger LZs. The display combination trends, although not statistically significant, show the PMD-PMD combination to be more erratic across all variables than both configurations in which the pilot uses the HMD.

6.3.3 Crash Rates (HMD/PMD: Approach and Landing)

An examination (by chi-square analysis) of the frequency of noncrash landings per attempts showed no significant differences due to display configuration or LZ size. Any frequency differences were deemed due to chance and not experimental conditions.

6.3.4 Discrete Activities (HMD/PMD: Approach and Landing)

6.3.4.1 Percent Time Narrow FOV Commanded

The pilot at the controls of the aircraft in this evaluation performed the majority of FOV selections. These selections were made mostly in the approach and touchdown phases. In these phases, HMD-PMD had the largest percentage of time in narrow FOV (25 percent) followed by HMD-HMD (2.1 percent) and PMD-PMD (0.8 percent).

6.3.4.2 Sensor Actuations per Run

The mean number of sensor actuations per run could only be calculated for the PMD-PMD runs using the manual sensor slew controls. Sensor usage data were not recorded while the sensor was controlled through the pilot's head movements. The frequency differences between pilot, copilot, and LZ difficulty were not significant. The overall number of sensor actuations per run was 4.8 at a mean checkpoint distance of 0.35 nmi.

TABLE 6-XV

HMD-PMD Evaluation: Touchdown Performance Trends

DISPLAY CONFIGURATION	LANDING ZONE SIZE AND TOUCHDOWN VARIABLES													
	LANDING TIME (SECONDS)		LANDING ERROR (FEET)		-X DRIFT (FT/S)		+X DRIFT (FT/S)		-Y DRIFT (FT/S)		+Y DRIFT (FT/S)		Z DRIFT (FT/S)	
	LARGE	SMALL	LARGE	SMALL	LARGE	SMALL	LARGE	SMALL	LARGE	SMALL	LARGE	SMALL	LARGE	SMALL
PMD-PMD	233	277	36	21	0.88	1.89	3.86	1.23	1.30	2.15	1.26	1.32	4.88	4.57
HMD-PMD	234	220	44	27	1.85	1.23	3.83	4.58	0.98	2.58	1.28	1.28	4.16	3.74
HMD-HMD	227	210	40	19	3.35	1.82	1.92	1.85	2.62	0.88	0.85	1.30	4.52	4.93

TABLE 6-XVI

HMD-PMD Evaluation: Relative Rankings of Touchdown Trends

DISPLAY CONFIGURATION	LANDING ZONE SIZE AND TOUCHDOWN VARIABLES														
	LANDING TIME (SECONDS)		LANDING ERROR (FEET)		-X DRIFT (FT/S)		+X DRIFT (FT/S)		-Y DRIFT (FT/S)		+Y DRIFT (FT/S)		Z DRIFT (FT/S)		OVERALL RANK
	LARGE	SMALL	LARGE	SMALL	LARGE	SMALL	LARGE	SMALL	LARGE	SMALL	LARGE	SMALL	LARGE	SMALL	
PMD-PMD	2	3	1	2	1	3	3	1	2	2	2	3	3	2	3*
HMD-PMD	3	2	3	3	2	1	2	3	1	3	3	1	1	1	2
HMD-HMD	1	1	2	1	3	2	1	2	3	1	1	2	2	3	1

*1 = BEST RANKING

TABLE 6-XVII

HMD-PMD Evaluation: Approach Performance Trends

DISPLAY CONFIGURATION	APPROACH VARIABLES		
	PERCENT UNDER 100 FEET	AVERAGE GROUNDSPEED	AVERAGE ALTITUDE
PMD-PMD	35.91	59.63	131.75
HMD-PMD	44.27	58.70	107.10
HMD-HMD	38.51	59.78	113.24

TABLE 6-XVIII

HMD-PMD Relative Rankings of Approach Trends

DISPLAY CONFIGURATION	APPROACH VARIABLES			OVERALL RANK
	PERCENT UNDER 100 FEET	AVERAGE GROUNDSPEED	AVERAGE ALTITUDE	
PMD-PMD	3	2	3	3*
HMD-PMD	1	3	1	1.5
HMD-HMD	2	1	2	1.5

*3 = WORST RANKING

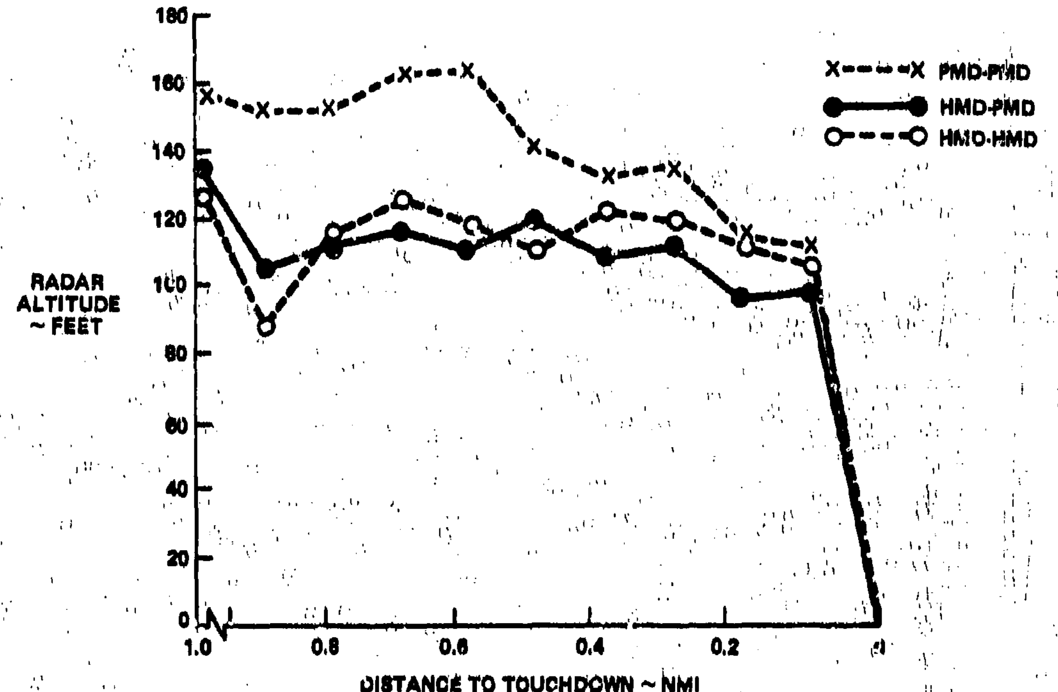

Figure 6-20. Radar Altitude during Landing Phase

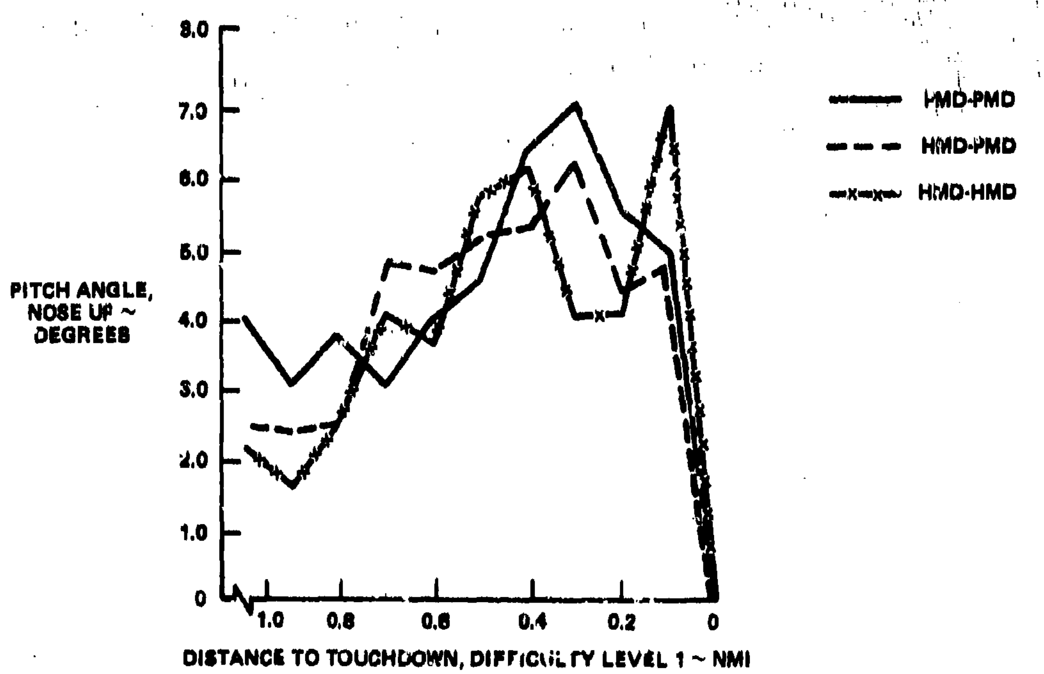

Figure 6-21. Pitch Angle during Landing Phase: Small LZ

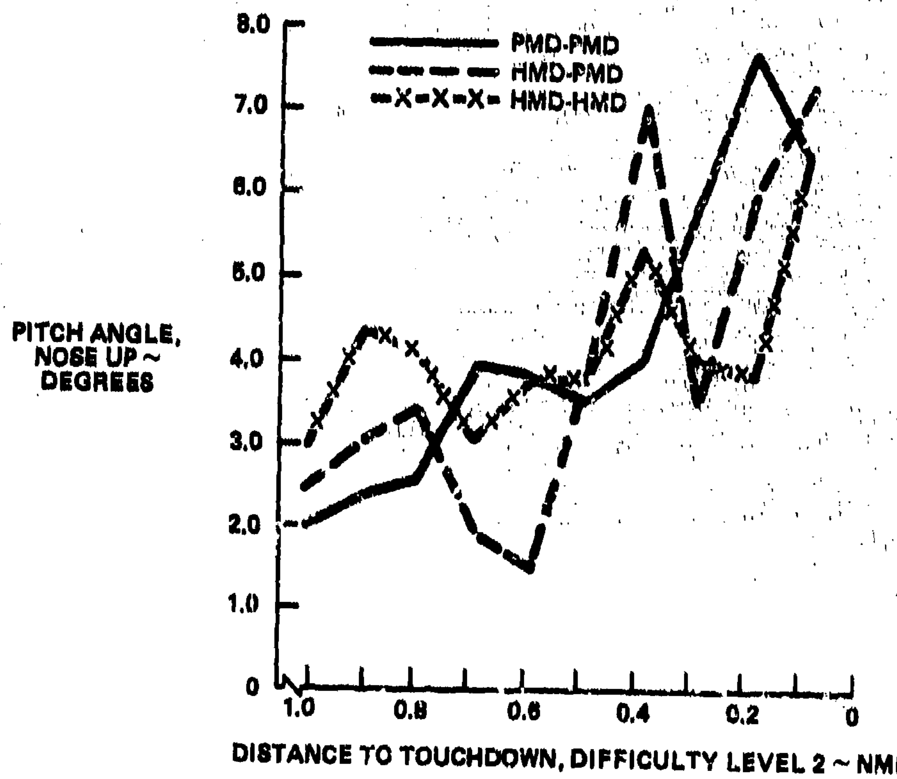

Figure 6-22. Pitch Angle during Landing Phase: Large LZ

6.3.4.3 Sensor Azimuth and Elevation

The crews in the HMD-PMD evaluation tended to spend more time with the sensor slewed off center than in the previous evaluations. This would result from the ease with which the pilot could slew the sensor while using the HMD. After sensor operation using the HMD, the pilot became accustomed to viewing the terrain and thus slewed the sensor more often manually when using the PMD. Figure 6-23 shows that the crews remained within 50 degrees of the center all of the time and remained centered 55 percent of the time in elevation. Figure 6-24 shows that they remained within 40 degrees of center all of the time, and remained centered 90 percent of the time in azimuth.

6.4 Enroute HMD-PMD-CDU Evaluation

Crew performance measures were obtained on longer routes at the 1200:1 scale emphasizing low level navigation with the three combinations of display units as well as CDU operation. Due to facilities difficulties during two pilot groups, data were collected on only four pilots at the 1200:1 scale. One of these pilots had to be eliminated for poor performance (i.e., enroute radar altitudes of over 1300 feet). Thus, statistical analysis is eliminated because of the sample size. Trends and indications discussed below must be qualified by the sample size.

6.4.1 Enroute Performance (HMD-PMD-CDU: Enroute)

No touchdown data were collected during this phase since enroute performance was the flight section under study. Table 6-XIX indicates lower altitudes for a higher percentage of time with the HMD-HMD display configuration. Table 6-XX shows a tendency for higher speeds with the HMD-PMD followed by the dual PMDs. The easier (flat) routes resulted in lower altitudes and higher speeds than the difficult (mountainous) routes. Routes involving a course change had higher altitudes and higher speeds than routes with no changes. The pilot did not have the verbal aid of the copilot while he was inserting a route change in the CDU. Thus, there was a tendency to fly higher over unfamiliar terrain. However, this also allowed higher groundspeeds on these longer routes.

6.4.2 Crash Rates (HMD-PMD-CDU: Enroute)

Chi-square analysis of the total attempts which resulted in successful runs showed the difference to be highly significant ($p = 0.0000$), i.e., the number of successful runs is due to display configuration combined with route difficulty. Examination of the independent variable (route difficulty) alone also resulted in significant differences in success frequencies. For the hard routes (mountainous terrain), HMD-HMD had the largest percentage of successful runs (50 percent), and PMD-PMD the smallest (25 percent). For easy routes (flat terrain), PMD-PMD had the largest percentage of successful runs (100 percent), and HMD-PMD the smallest (43

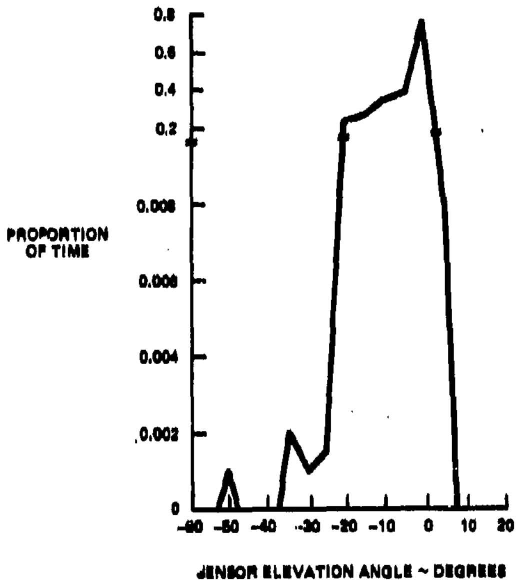

Figure 6-23. PMD Sensor Elevation Gimbal Angle Distributions

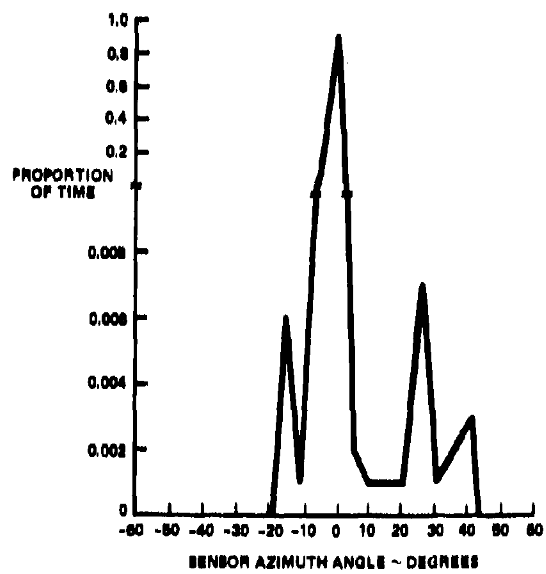

Figure 6-24. PMD Sensor Azimuth Gimbal Angle Distributions

TABLE 6-XIX

HMD-PMD Evaluation: Average Altitude Enroute

	DIFFICULT ROUTE		EASY ROUTE		
	NO ROUTE CHANGE	ROUTE CHANGE	NO ROUTE CHANGE	ROUTE CHANGE	OVERALL MEAN
PMD-PMD	167.19 (6%)*	167.80 (19%)	161.87 (23%)	178.91 (19%)	173.19
HMD-PMD	167.90 (18%)	143.91 (26%)	148.59 (23%)	214.41 (11%)	168.70
HMD-HMD	165.41 (25%)	170.15 (22%)	145.45 (31%)	144.05 (21%)	156.27

*PERCENTAGE OF TIME UNDER 100 FEET

TABLE 6-XX

HMD-PMD Evaluation:
Average Groundspeed
Enroute (Knots)

	DIFFICULT ROUTE		EASY ROUTE		
	NO ROUTE CHANGE	ROUTE CHANGE	NO ROUTE CHANGE	ROUTE CHANGE	OVERALL MEAN
PMD-PMD	66	59	66	69	65
HMD-PMD	56	70	64	76	67
HMD-HMD	68	64	56	67	63.5

percent). Examination of display configuration alone resulted in no significant differences. When pilot workload is increased (i.e., mountainous terrain), the HMD for the pilot has a higher success rate.

6.4.3 Discrete Activities (HMD-PMD-CDU: Enroute)

6.4.3.1 Percent Time Narrow FOV Commanded

The crews made very few FOV selections in this evaluation. Selections were evenly divided between pilot and copilot, clustered in the PMD-PMD configuration and in the no route change conditions. The largest percentage of time in narrow FOV was less than 1.0 percent in the PMD-PMD combination. The enroute evaluation crews apparently found little or no need for the narrow FOV regardless of the display configuration.

6.4.3.2 Sensor Actuations per Run

The mean number of sensor actuations per run was calculated for the PMD-PMD configuration. The pilots slewed the sensor (21.5 per run) significantly more than the copilots (2.54 per run) and tended to slew more often in the flights with a route change. This group of pilots performed their 1200:1 runs first, and learned to operate the PMD and HMD display combinations simultaneously. Therefore, the crews became accustomed to having the pilot in control of the sensor. The mean sensor slewing distance to the next checkpoint was 2.14 nmi and did not vary by experimental conditon, again indicating that sensor slewing occurs primarily for terrain avoidance as opposed to checkpoint identification. It should be noted that this group of subject pilots slewed the sensor overall more than pilots from previous phases in comparable routes. The HNVS Final Report (Reference 5) indicates an overall slew rate of 12 times per run, this evaluation shows 19 times per run for the pilots.

6.4.3.3 Sensor Azimuth and Elevation

The crews tended to slew the sensor less frequently enroute than in approach and landing. In azimuth they remained centered more in the difficult routes than the easy routes. In difficult routes, they remained centered 94 percent of the time with no route change and 84 percent of the time with a change. In easy routes they remained centered with a route change 76 percent of the time and 72 percent with no route change. The pattern in elevation is the same for difficult routes but they remained centered 97 percent in easy routes with a change and 88 percent without.

6.4.3.4 CDU Operation

All enroute data runs required the copilot to manually capture the LZ. This required a specific three key operation of the flight plan master function key (MFK) and line keyes 9 and 6. Most runs had an addendum to this sequence of several scale changes (line keys 11 and 12). Discrete data were examined to determine actual sequences. There were 2 errors out

of 17 operations in the performance of this sequence, both involving parallax problems with line key 9. One copilot used key 8 instead of 9 and one used 10.

The experimental variable of route change also involved a specific sequence of events to properly execute the new route and capture checkpoints in the old. The display configuration of PMD-PMD had the fewest CDU errors (6), followed by HMD-HMD (7) and HMD-PMD (11). There were 11 line key errors and 13 total MFK errors encountered during route changes. Tables 6-XXI and 6-XXII display the type of errors that occured. These tables show consistent problems of parallax and misunderstanding of key functions. They depressed line keys several times in succession in an effort to obtain a response or to correct an error. The copilots did not cue in on the CDU feedback (for example, the asterisk which appears with the capture function).

6.5 Approach and Landing Virtual HUD Evaluation

The cockpit was equipped with a display combination of the copilot on virtual HUD and the pilot at the controls of the aircraft on HMD. The analysis for virtual HUD evaluation was limited to one pilot group of four pilots. This resulted in 24 runs each for the 240:1 and 1200:1 scales. The statistical analysis was affected by small sample sizes. The significant effects found must be qualified with the small sample size and its effects on the statistical sensitivity.

6.5.1 Touchdown Data (Virtual HUD: Approach and Landing)

The results in Table 6-XXIII indicate the only significant differences to be in the X drift (positive) as a function of LZ size and in the enroute variables of percent of time under 100 feet, and the average radar altitude. Tables 6-XXIV through 6-XXVI show how these differences are distributed within the experimental conditions. Examination of display configurations alone without zone size shows the virtual HUD configuration resulted in the highest percentage of time under 100 feet and the lowest radar altitude followed by the common video and HMD-PMD combinations respectively. The common HMD video resulted in the fastest groundspeed. The HMD-PMD combination had the best overall ranking on touchdown performance trends, followed closely by the common HMD video. During the approach phase, both HMD configurations performed better than the HMD-PMD configuration.

6.5.2 Smoothness of Approach and Landing (Virtual HUD: Approach and Landing)

The regression analyses resulted in no significant differences in the residual mean squares between the display combinations. The trends in the approach distributions show the HMD-HMD common video condition to have the smoothest approach across time and distance in rate of descent and radar altitude. The remaining variables were not consistent for both time and distance.

TABLE 6-XXI

Line Key Errors during Route Changes

FREQUENCY	ERROR SEQUENCE
4	DEPRESSED LINE KEY 8 INSTEAD OF 9
1	DEPRESSED LINE KEY 4 INSTEAD OF 3
2	DEPRESSED LINE KEY 10 INSTEAD OF 9
1	DEPRESSED LINE KEY 2 INSTEAD OF 3
2	SEVERAL LINE KEY ENGAGES AFTER ONE MFK
1	SEVERAL PAGE CHANGES AFTER ONE DIR

TABLE 6-XXII

Master Function Key Errors during Route Changes

FREQUENCY	ERROR SEQUENCE
3	DEPRESSED FTL/PLN INSTEAD OF DIR
2	DEPRESSED MARK INSTEAD OF FTL/PLN
3	DEPRESSED STAT INSTEAD OF DIR
2	DEPRESSED PROG INSTEAD OF DIR
2	DEPRESSED MARK INSTEAD OF DIR
1	DEPRESSED MAP/RTN INSTEAD OF FLT/PLN

TABLE 6–XXIII

Pilot Performance in Virtual HUD Evaluation:
Touchdown and Approach

DEPENDENT VARIABLES	OVERALL MEAN	STANDARD DEVIATION	INDEPENDENT VARIABLES		
			DISPLAY CONFIGURATION	DIFFICULTY LEVEL	INTERACTION
TOUCHDOWN:					
LANDING TIME	200.90S	56.57	NS**	NS	NS
RADIAL LANDING ERROR	15.14 FT	65	NS	NS	NS
–X DRIFT	–1.76 FT/S	1.58	NS	NS	NS
+X DRIFT	+1.53 FT/S	1.16	NS	p = 0.5[illegible]	NS
–Y DRIFT	–0.58 FT/S	0.33	NS	NS	NS
+Y DRIFT	+1.01 FT/S	0.78	NS	NS	NS
Z DRIFT	3.029 FT/S	2.23	NS	NS	NS
APPROACH:					
PERCENT UNDER 100 FEET	57.86 %	24.53	p = 0.055	LANDING ZONE DOES NOT AFFECT APPROACH VARIABLES	
AVERAGE GROUNDSPEED	66.03 KN	6.2	NS		
AVERAGE ALTITUDE	93.13 FT	17.85	p = 0.072		

*SIGNIFICANCE LEVELS LIMITED TO $p < 0.10$
**DIFFERENCE NOT SIGNIFICANT

TABLE 6–XXIV

Virtual HUD Evaluation: Significant Touchdown and Approach Performance

DISPLAY CONFIGURATION	PERFORMANCE VARIABLE AND LANDING ZONE SIZE					
	+X DRIFT		PERCENT OF TIME UNDER 100 FEET		AVERAGE RADAR ALTITUDE	
	LARGE	SMALL	LARGE	SMALL	LARGE	SMALL
HMD-FMD	1.09	1.31	25.95	65.66	116.48	88.35
HMD-HMD (COMMON VIDEO)	1.07	3.74	38.50	74.65	104.34	77.53
HMD-HMD (VIRTUAL HUD)	1.42	1.58	80.75	58.75	77.73	93.34

TABLE 6–XXV

Virtual HUD Evaluation: Relative Rankings of Touchdown Performance Data

DISPLAY CONFIGURATION	PERFORMANCE VARIABLE AND LANDING ZONE SIZE														
	−X DRIFT		+X DRIFT		−Y DRIFT		+Y DRIFT		Z DRIFT		LANDING TIME		LANDING ERROR		OVERALL RANK
	LARGE	SMALL	LARGE	SMALL	LARGE	SMALL	LARGE	SMALL	LARGE	SMALL	LARGE	SMALL	LARGE	SMALL	
HMD-FMD	2	1	2	1	1.5	1	1.5	1.5	2	2	1	3	3	1	1*
HMD-HMD (COMMON VIDEO)	1	3	1	3	1.5	2	3	1.5	1	1	2	2	2	3	2
HMD-HMD (VIRTUAL HUD)	3	2	3	2	3	3	1.5	3	3	3	3	1	1	2	3

*1 = BEST RANKING

TABLE 6–XXVI

Virtual HUD Evaluation: Relative Rankings of Approach Performance Data

DISPLAY CONFIGURATION	PERFORMANCE VARIABLE			OVERALL RANK
	PERCENT OF TIME UNDER 100 FEET	AVERAGE RADAR ALTITUDE	AVERAGE GROUNDSPEED	
HMD-FMD	3	3	2	3*
HMD-HMD (COMMON VIDEO)	2	2	1	1.5
HMD-HMD (VIRTUAL HUD)	1	1	3	1.5

*3 = WORST RANKING

6.5.3 Crash Rates

Chi-square results indicated a significantly ($p = 0.004$) larger percentage of crashes per attempts for the HMD-PMD configuration (55 percent) than the common HMD video (30 percent) or the virtual HUD (27 percent) configurations. The frequency of technical poor landings was three for each display configuration with the majority due to rate of descent (2 drift). There were no technical crashes.

6.5.4 Discrete Activities (Virtual HUD: Approach and Landing)

6.5.4.1 Percent Time Narrow FOV Commanded

The crews used the FOV command in only one condition (HMD-PMD, large landing zone). This resulted in a rate of less than 1 percent in the narrow FOV for pilot and copilot.

6.6 Enroute Virtual HUD Evaluation

The statistical analysis for this phase was again based on 24 runs at the 1200:1 scale. The small sample size resulted in greater statistical impact during the enroute phase due to the additional variable under study, i.e., fewer data runs in each treatment condition.

6.6.1 Enroute Performance (Virtual HUD: Enroute)

The ANOVA results shown in Table 6-XXVII indicate that the variable of route change has a significant effect on percentage of time under 100 feet and average groundspeed. Runs without route changes had a higher percentage under 100 feet with the virtual HUD configuration (73.5 percent) followed by common HMD video (57.5 percent) (Table 6-XXVIII). In runs with a route change, the HMD-PMD configuration had the highest percentage of time under 100 feet (56 percent). Overall, the HMD configuration with the virtual HUD had the lowest average radar altitude. However, the variability between display combinations is small, i.e., only 11 feet.

Runs with a route change had faster average groundspeeds than those without (Table 6-XXIX). This was predictable since the altitudes of changed routes tended to be higher, allowing faster average groundspeeds. The virtual HUD had the fastest groundspeed in runs with changes and the lowest in runs without. Overall, the common HMD video had the fastest average groundspeed.

6.6.2 Crash Rates (Virtual HUD: Enroute)

The Chi-square results indicate significant frequency differences in the percentage of crashes per total attempts. In all display configurations, the hard routes contained the highest ($p < 0.05$) percentage of crashes (HMD-PMD 75 percent, common HMD video 50 percent, and virtual HUD 60 percent). The route change conditions contained the highest percentage

TABLE 6-XXVII

Pilot Performance in Virtual HUD Evaluation: Enroute*

DEPENDENT VARIABLES	OVERALL MEAN	STANDARD DEVIATION	INDEPENDENT VARIABLES			
			DISPLAY CONFIGURATION	ROUTE DIFFICULTY	ROUTE CHANGE	INTERACTION
PERCENT UNDER 100 FEET	55.34 %	14.42	NS**	NS	p = 0.01	NS
AVERAGE GROUNDSPEED	69.10 KN	16.01	NS	NS	p = 0.02	NS
AVERAGE ALTITUDE	104.99 FT	17.18	NS	NS	NS	NS

*SIGNIFICANCE LEVEL LIMITED TO $p \leq 0.10$
**DIFFERENCES NOT SIGNIFICANT

TABLE 6-XXVIII

Virtual HUD Evaluation: Average Altitude
Enroute

DISPLAY COMBINATION	DIFFICULT ROUTE		EASY ROUTE		OVERALL MEAN
	NO ROUTE CHANGE	ROUTE CHANGE	NO ROUTE CHANGE	ROUTE CHANGE	
HMD-PMD	120.56 (42%)*	105.06 (56%)	95.04 (62%)	125.10 (37.5%)	111.45
HMD-HMD (COMMON VIDEO)	93.39 (62%)	118.18 (45%)	112.45 (57.5%)	106.02 (54%)	107.51
HMD-HMD (VIRTUAL HUD)	84.06 (73.5%)	113.00 (47%)	83.11 (73.5%)	122.86 (37.5%)	100.75

*PERCENT OF TIME UNDER 100 FEET

TABLE 6-XXIX

Virtual HUD Evaluation: Average Groundspeed Enroute

DISPLAY COMBINATION	DIFFICULT ROUTE		EASY ROUTE		OVERALL MEAN
	NO ROUTE CHANGE	ROUTE CHANGE	NO ROUTE CHANGE	ROUTE CHANGE	
HMD-PMD	68.10	67.06	65.94	69.90	67.76
HMD-HMD (COMMON VIDEO)	71.85	64.97	73.01	85.76	73.83
HMD-HMD (VIRTUAL HUD)	62.46	60.84	65.14	65.86	66.61

of crashes per attempts within difficulty levels with the exception of the HMD-PMD hard route. The virtual HUD configuration had a higher percentage of good runs per attempts (40 percent) than the common video (46 percent) or HMD-PMD (46 percent) conditions.

6.6.3 Discrete Activities (Virtual HUD: Enroute)

6.6.3.1 Percent Time Narrow FOV Commanded

The pilots made all of the FOV commands and enabled the narrow FOV more times in routes with changes than without and more often in difficult routes than easy. The largest percentage of time was 9.2 percent with common HMD video, difficult route with change. No pilot used the narrow FOV while the copilot had a PMD display. The mean distance to the next checkpoint was 1.73 nmi.

6.6.3.2 CDU Operation

Discrete actions were examined to evaluate the sequence of key actuations used to manually capture the LZ on all runs. The sequence errors were dispersed between the display combinations, but clustered in the route change conditions. The most common error was depressing line key 5 instead of 6 followed by more than one line key depression after a function key.

Review of the CDU route change key sequence requirements revealed the majority of errors (seven) to be in the HMD-PMD configuration on a difficult route followed by HMD virtual HUD on an easy route (three) and HMD-PMD, easy route (two). The common HMD video and virtual HUD difficult routes had no errors. Tables 6-XXX and XXXI indicate the sequence and type of errors encountered during route changes. These tables reveal parallax problems and key function misunderstanding.

6.7 Summary

The size of the landing zones affected pilot performance more consistently and predictably than any other factor. The smaller zones required more precise maneuvering that resulted in longer land times, higher radar altitudes during approach, smaller radial error, etc. To land in these zones, the pilot must have the helicopter under control, requiring precise information processing.

The symbology phase results indicated the hover symbology set to be the most consistent in its results. The flight symbology was needed up to approximately 0.3 nmi from the touchdown point, the transition symbology until 0.05 to 0.03 nmi from touchdown, and the hover symbology 0.03 nmi to touchdown. The transition symbology gave the pilots the extra information needed for precise landings.

The narrow FOV results in inconsistent pilot performance when approaching the landing zones as compared to the wide and dual FOV. Pilots

TABLE 6-XXX

Master Function Key Errors during Route Changes

FREQUENCY	ERROR SEQUENCE
1	DEPRESSED DIR INSTEAD OF FLT/PLN
3	DEPRESSED FLT/PLN INSTEAD OF DIR

TABLE 6-XXXI

Line Key Errors during Route Changes

FREQUENCY	ERROR SEQUENCE
3	SEVERAL LINE KEY ENGAGES AFTER ONE FUNCTION KEY
1	DEPRESSED LINE KEY 11 BEFORE DIR
1	DEPRESSED LINE KEY 4 INSTEAD OF 5
1	DEPRESSED LINE KEY 4 INSTEAD OF 9
2	GENERAL CONFUSION OF KEY FUNCTIONS

were unable to smoothly approach the zone when forced to use the narrow FOV. The dual FOV capability resulted in a minimal amount of time in narrow FOV. The apparent low usage rate could indicate that for this specific low level navigation mission, pilots did not find the information provided by the narrow FOV helpful in performing the specific tasks required of the pilots as evidenced in performance differences. The narrow FOV required a higher sensor usage rate to compensate for the lack of information.

The pilots in the HMD-PMD evaluation generally performed better using the HMD. The ease of slewing the sensor allowed the pilots to examine terrain features and maintain low altitude with comparative ease. The pilots' landing approach and touchdown was smoother when using the HMD. During the enroute portion, the crew performance in flatter terrain was slightly better while the pilot used the PMD, but performance in mountainous terrain was better with the pilot on the HMD.

During low level landing zone approach, the copilot display has an inconsistent effect on performance measures. His workload during this phase is critical to navigation, terrain avoidance, and general pilot assistance. During the enroute phase he can perform well with the HMD and the PMD. It appears to be the pilot's display that has the greater impact on performance measures.

The virtual HUD evaluation varied the copilot display combinations from PMD, HMD, and HMD virtual HUD while the pilot remained on the HMD. During critical approach to landing, the copilot tends to perform better with the HMD. During touchdown the copilot performs better with the PMD. During the enroute phase, crew performance was best with the HMD for the copilot with or without the virtual HUD. The differences between the three display combinations are slight and indicate that the task pressures felt by the copilot may be the critical factor.

During landings, the sensor remained centered 90 percent of the time in azimuth and 55 percent of the time in elevation. Maximum sensor gimbal angle used during the evaluation was 60 degrees in azimuth and 60 degrees down in elevation. The sensor was never slewed up in elevation.

The copilots' operation of the CDU indicated that it is a workable part of the system, without overburdening the copilot. The errors indicate a necessity for correction of the display alignment and CDU feedback when a function key is initialized.

6.8 Subject Pilots

Tables 6-XXXII and 6-XXXIII contain the overall performance altitudes for the pilots participating in the research. They have been ranked from the lowest altitude (best performance) to the highest (worst performance). Their performance was correlated with their actual flight hours. There is no correlation between simulation performance and flight hours.

TABLE 6-XXXII

Relative Rankings of Crews Based on Average Altitude (240:1)

ALTITUDE RANK		AVERAGE ALTITUDE	FLIGHT HOURS
1	(S)*	68.38	615
2	(S)	76.80	502
3	(V)*	77.42	450
4	(S)	81.86	535
5	(H)*	82.11	570
6	(V)	87.12	451
7	(H)	87.95	470
8	(S)	88.11	480
9	(S)	89.68	1200
10	(S)	92.40	502
11	(S)	92.80	585
12	(H)	95.76	310
13	(S)	98.52	380
14	(V)	99.86	585
15	(S)	100.53	680
16	(F)*	100.75	800
17	(H)	103.20	450
18	(F)	103.95	270
19	(H)	104.65	625
20	(V)	104.95	440
21	(S)	105.06	523
22	(F)	105.64	4000
23	(F)	106.13	520
24	(S)	106.53	501
25	(H)	109.06	590
26	(F)	110.14	500
27	(F)	111.96	2900
28	(H)	113.91	500
29	(H)	117.36	487.7
30	(F)	124.38	520
31	(H)	124.93	300
32	(F)	125.66	400
33	(H)	136.44	320
34	(H)	146.16	520
35	(H)	242.50	498

*S = SYMBOLOGY
V = VIRTUAL HUD
H = HMD/PMD
F = FIELD OF VIEW

TABLE 6-XXXIII

Relative Rankings of Crews Based on Average Altitude (1200:1)

ALTITUDE RANK	AVERAGE ALTITUDE	FLIGHT HOURS
1 (V)*	91.61	440
2 (V)	93.54	451
3 (V)	118.28	585
4 (V)	122.82	450
5 (H)*	142.86	487.7
6 (H)	167.48	310
7 (H)	170.63	320
8 (H)	234.78	498

*V = VIRTUAL HUD
H = HMD/PMD/CDU

All of the pilots had to learn the new system and develop new crew interactions and scan patterns. Their attitudes and learning abilities had more performance effects than anything else.

7.0 PILOT OPINION RESULTS

7.1 General

All research participants responded to extensive questionnaires dealing with the simulation facilities, concepts under study, and recommended changes to the HNVS configuration.

7.1.1 Simulator Orientation

The majority of pilots (82 to 91 percent) felt the briefing upon arrival was adequate, as were the cockpit checkout and mission briefing materials. Ten hours of cockpit training were recommended.

7.1.2 Simulator Realism

The cockpit, aero model, force feel, and motion base received generally average ratings on their individual components. The terrain model had high ratings on its realism and cultural features. The overall simulation rating was 4.2 with 5 being the highest rating possible. General simulation comments made by four or more of the 35 pilots were as follows:

1 Needs better ventilation (gets hot)

2 Didn't notice any wind effects

3 The only time the motion base seemed to simulate actual flight was during turbulence; it could use engine noise and vibration

4 Overall, the simulator and terrain model were excellent except for the few minor environmental problems listed previously.

7.1.3 Symbols

The digital heading display was helpful to 78 percent of the pilots, and 22 percent has a neutral reaction to it. General symbology comments indicated by four or more pilots were as follows:

1 Legibility was good

2 Size was good

3 Contrast was adequate to good

4 Movement was good

5 Sensitivity to flight control was good

6 Digital readout change rate was good.

Pilot comments specific to the symbology formats were as follows:

1 Flight:

a Analog Scale-Increase thickness, limit to 200 feet AGL, move to the left of screen, box altitude like the digital heading

b Need turn and slip indicator in bottom center of screen (most pilots)

c Need angle of bank indicator

d Corridor line not necessary

e Optional altitude bar distracting and not used

f Torque Indicator-Analog not necessary, digital readout gives enough feedback

g Increase groundspeed size

h Put 100 foot hash marks on rate of climb.

2 Hover:

a Add turn and slip indicator

b Add hash marks in center of screen to indicate airspeed relative to length of hover velocity vector.

7.1.4 Controls

Sixty-six percent of the pilots would not like to move any of the control panels. Sixty-two percent would not move any control locations. Regarding control operations, 64 percent would not make any changes in functions, 80 percent would not change control movements, and 67 percent would not change the sensitivity. Control labels would not be changed by 97 percent, and the present design was acceptable to 86 percent. The comments made by four or more pilots regarding controls are as follows:

1 Recommend changing the location of the FOV select and Hover Position select: FOV to the collective, Hover Position to the FOV select position, or just exchange location of FOV and position box

2 Change sensing of sensor control switch; forward should slew sensor down, back should slew sensor up

3 Collective is slow to respond.

7.1.5 General Critique

General comments made by four or more pilots were:

1 Familiarization with the terrain makes navigation easier (10 pilots)

2 Familiarization with the terrain equals real world briefing situations (six pilots)

3 Aural warning signal to indicate low altitude would make mission easier and safer

4 Need extensive training

5 External visual cues should be used: in an actual mission you would be able to see outside to some degree to help you fly.

7.1.6 Instrument Monitoring, Importance and Lighting

All pilots monitored the PMD continuously and considered it very important. Fifty-nine percent of the pilots monitored the CDU occasionally and considered it important. The majority of pilots monitored the remaining instruments only occasionally or not at all and considered them only moderately important.

Sixty-seven percent of the copilots monitored the PMD continuously and the remainder of copilots only frequently. They considered it important to very important. All of the copilots monitored the CDU frequently to continuously and considered it to be very important. The remaining panel instruments were monitored occasionally or never by a majority of the copilots. These instruments were considered to be of only moderate importance.

The cockpit instruments were grouped into lighted groups (Table 7-I) that could be dimmed or turned off. Of the pilots and copilots assessing only PMD conditions, about 35 percent turned off lighting group 1 and about 30 percent turned off lighting group 2. Most felt the electromechanical instruments were not necessary with the PMD and CDU. Most pilots (92 percent) turned off lighting group 2 while using the HMD. This group of pilots also dimmed the CDU. The copilots wearing the HMD dimmed lighting group 1 (67 percent) and group 2 (75 percent). Overall, copilots tended to dim cockpit lights rather than turn them off more than pilots. It was part of the copilot's task allocations to perform functions in the cockpit requiring some level of lighting.

Comments made by four or more pilots regarding instrumentation were:

1 Only required PMD information and as little lighting as possible

2 PMD red filter: no effect (half), helpful (half)

TABLE 7-I

Cockpit Instrument Lighting Groups

GROUP 1	GROUP 2
AIRSPEED	TRIPLE TACH
TURN AND SLIP	TORQUEMETER
BARO ALTITUDE	RADAR ALTITUDE
CLOCK	ALTITUDE
	BDHI
	VSI
	CDU

3 Dimmed lights to reduce distraction but still able to use as backup

4 All lights had to be off or very low when using the HMD

5 PMD should have emergency inputs when needed so no instruments are needed

6 Exchange locations of the bearing distance heading indicator and the Radar ALT for both pilot and copilot

7 Put HNVS control on instrument panel below PMD

8 Delete CORR and ALT ON

9 Had to scan the turn and bank indicator to supplement the PMD

10 Put barrier on copilot's PMD so light does not distract pilot on HMD

11 Have emergency information and engine information available on PMD or CDU so no additional instruments are needed.

7.1.7 Task Allocations and Crew Techniques

The recommended task allocations (Table 7-II) were acceptable to the majority of pilots participating. Additions and changes indicated were as follows:

1 Copilot monitor airspeed and aircraft trends

2 Copilot monitor vertical speed indicator and altitude during hover and landing

3 Copilot has to navigate.

Opinions on sharing sensor field of view and slewing varied with each pilot group. Several crews allowed only the pilot to slew the sensor, the copilot had to request the pilot to slew when necessary. Other crews allowed the copilot to slew the sensor only if he warned the pilot but never during a hover. A few crews allowed the copilot total sensor control and the pilot would request slewing. Individual flight crews quickly developed their own techniques. Most crews had the pilot control field of view; however, this function was rarely used.

The participants felt the pilot's primary duty was to fly the aircraft. Extensive information was transferred verbally from the copilot to the pilot. The result was a constant dialogue between them regarding all flight information.

TABLE 7-II

Recommended Task Allocations

COPILOT	PILOT
RECOMMEND HEADINGS	SELECT IDEAL PATH
POINT OUT CHECKPOINTS	CONTROL ALTITUDE AIRSPEED POWER
DESCRIBE ANTICIPATED TERRAIN RELIEF TERRAIN FEATURES TERRAIN ALTITUDE	
WARN OF LOW ALTITUDE	PRIMARY SENSOR CONTROL
WARN PILOT BEFORE SLEWING	

7.1.8 Overall Mission Ratings

All participants in the 240:1 scale evaluations rated the mission ease and safety in three terrain types. The results were predictable: missions were significantly ($p < 0.05$) safer and easier in flat terrian followed by rolling hills and mountainous terrain (Figures 7-1 and 7-2).

7.2 Approach and Landing Symbology Evaluation

According to 82 percent of the pilots, sufficient time was spent training for approach and landing with the four symbology sets. Several pilots requested more initial training on hovering and landing.

Pilots were asked to rate the ease and safety of approaches, landings, and takeoffs with each of the four symbology sets. These ratings are shown in Figures 7-3 through 7-8. The ease and safety of the flight symbology in the approach phase was predictable since it imparts necessary enroute information. The transition symbology also gives desired enroute feedback. The ratings were tested for significant differences by using a T-test for significant differences between the means. Significant differences ($p < 0.05$) were found between the hover and flight and between the hover meter and flight symbology for safety and ease of landing in small and very small zones. Examination of symbology ratings alone indicated the hover to be the easiest and safest at landing followed by the hover meter, the window box, and flight symbology sets ($p < 0.05$). The significant ($p < 0.05$) rating trends at takeoff were essentially the same, the exception being a slightly higher rating for the flight symbology over the window box.

Comments by four or more pilots in this symbology evaluation phase were as follows:

1 Sensor slewing during landings tends to disorient

2 Copilot should keep track of airspeed

3 Only pilot performed sensor slewing (five crews)

4 Only copilot performed sensor slewing (five crews)

5 Field-of-regard adequate for transport mission: good

6 Field-of-view change left up to pilot in command

7 Copilot slewing sensor without warning causes pilot vertigo

8 Panel mounted display location good (eight crews)

9 Display size good

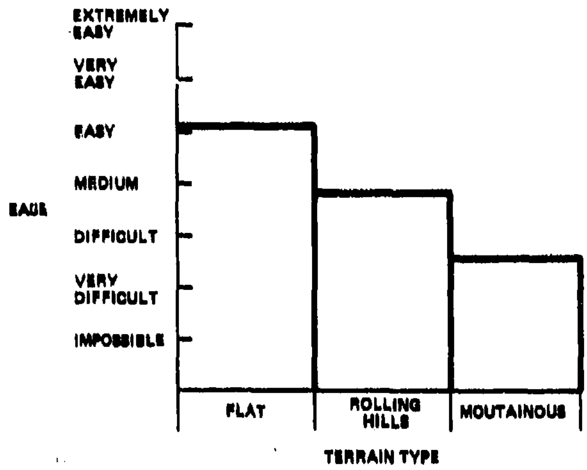

Figure 7-1. Ease of Actual Mission: All 240:1 Evaluations Combined

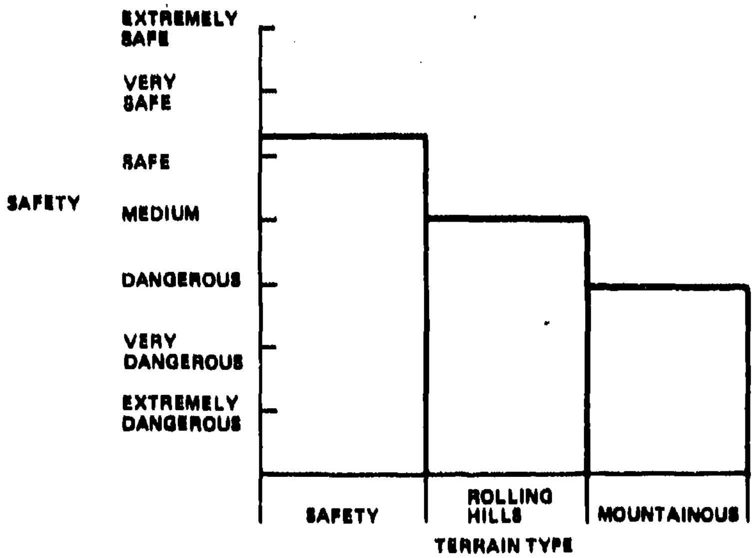

Figure 7-2. Safety of Actual Mission: All 240:1 Evaluations Combined

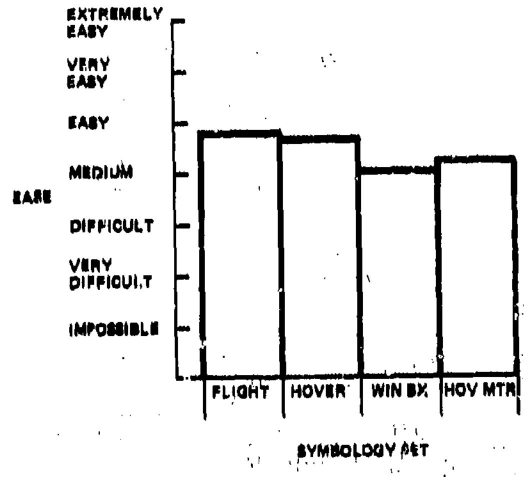

Figure 7-3. Ease of Approach to LZ

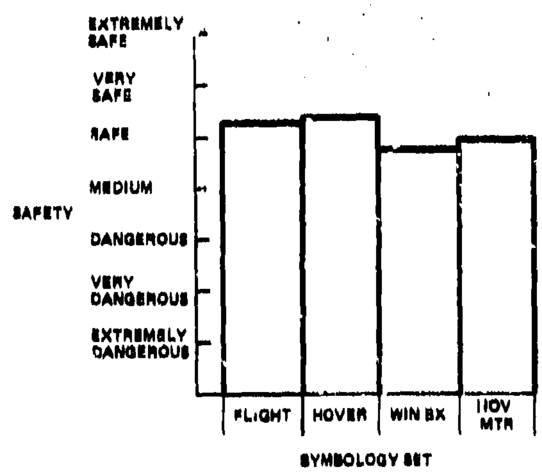

Figure 7-4. Safety of Approach to LZ

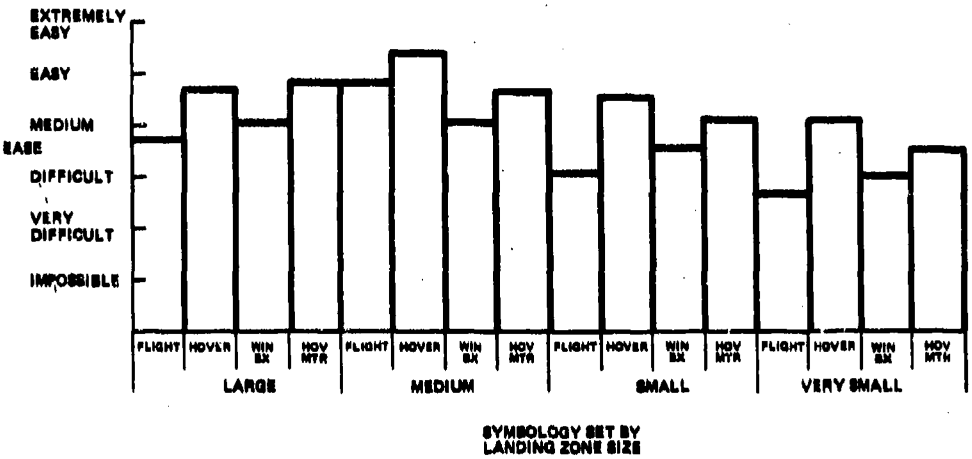

Figure 7-5. Ease of Landing

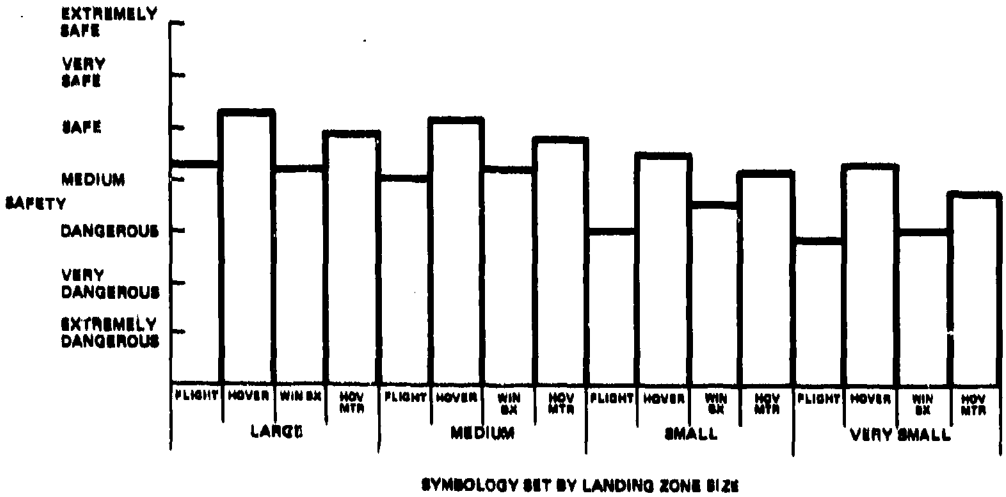

Figure 7-6. Safety of Landing

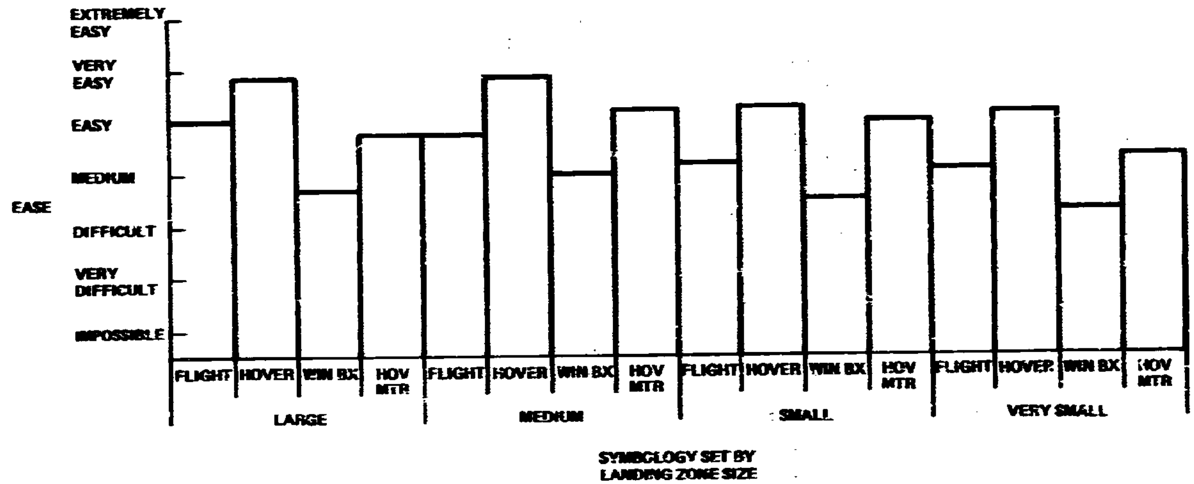

Figure 7-7. Ease of Takeoff

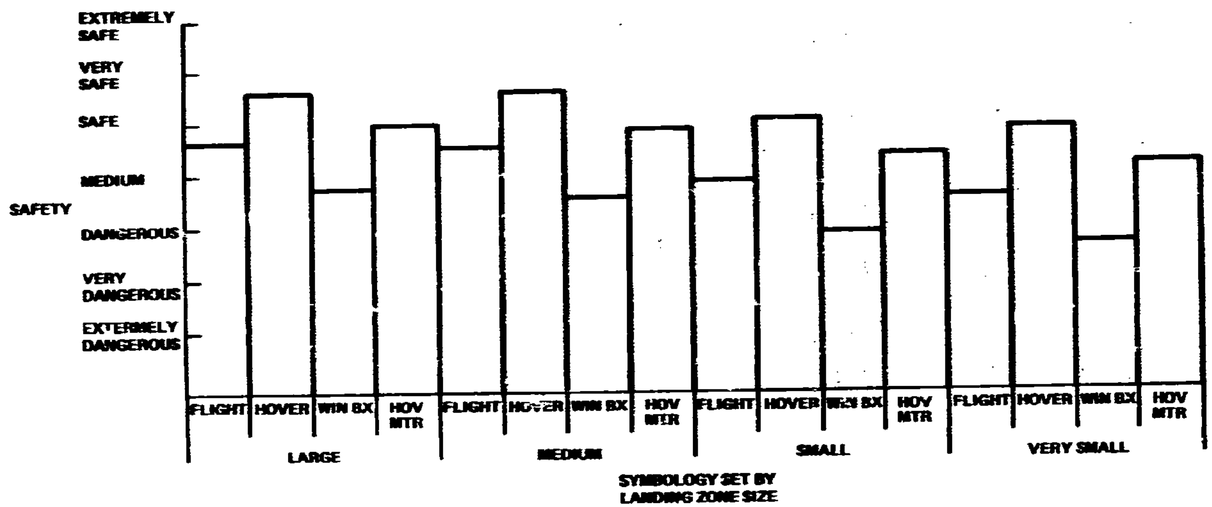

Figure 7-8. Safety of Takeoff

10 Display resolution fuzzy, needs contrast (six crews), good (three crews)

11 Color and lighting for display and instruments fine

12 Sensor: elevation sensing backward.

7.3 Approach and Landing Field of View Evaluation

All pilots (N=8) in this evaluation felt enough time was spent on approaches and landings with the different fields of view.

The pilot ratings of ease and safety of the fields of view in approaches, landings, and takeoffs are shown in Figures 7-9 through 7-14. In approaches to the landing zone, the narrow field of view was considered significantly more dangerous and difficult than wide and dual field of view.

In the landing phase, pilots preferred the wide and dual fields of view consistently over the narrow. The pilots in this evaluation did not rate any field of view as easy or safe, ratings were generally lower than in the symbology evaluation. The preference trends were the same in the takeoff phase. This phase was considered slightly easier and safer than the landing or approach phases.

Comments made by three or four pilots in the field of view evaluation phase were as follows:

1 Copilot did sensor slewing

2 Helmet mounted display gimballed sensor would simplify task

3 Field of view controlled by pilot

4 No instrument lights turned off

5 Panel mounted display location good

6 Display size good.

7.4 Approach and Landing HMD-PMD Evaluation

Eighty-three percent of the participants felt enough time was spent training on the display configurations. The majority of pilots using the HMD felt that the field of regard was adequate for the transport mission.

The pilots rated ease and safety of display configurations during approaches, landings, and takeoffs (Figures 7-15 through 7-20). There was little response variability; however, consistent trends were apparent. The HMD for the pilot is rated safer and easier than dual PMDs in all phases.

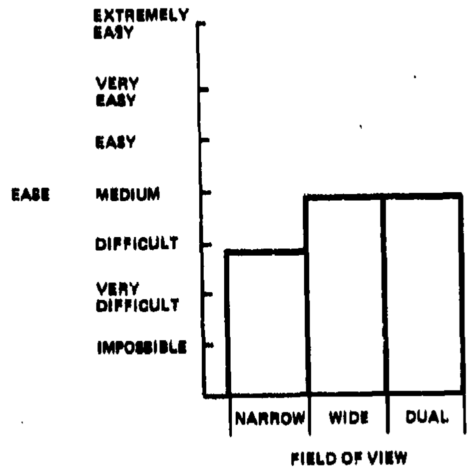

Figure 7-9. Ease of Approach to LZ

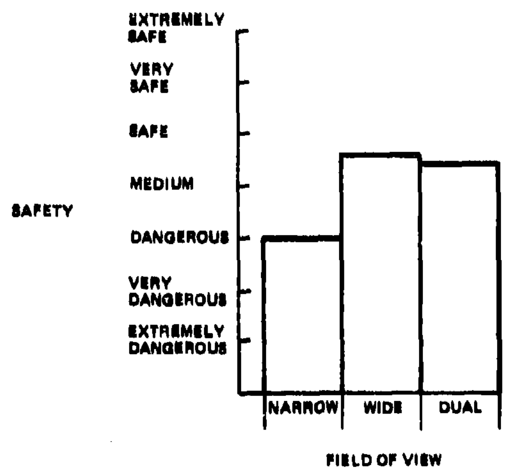

Figure 7-10. Safety of Approach to LZ

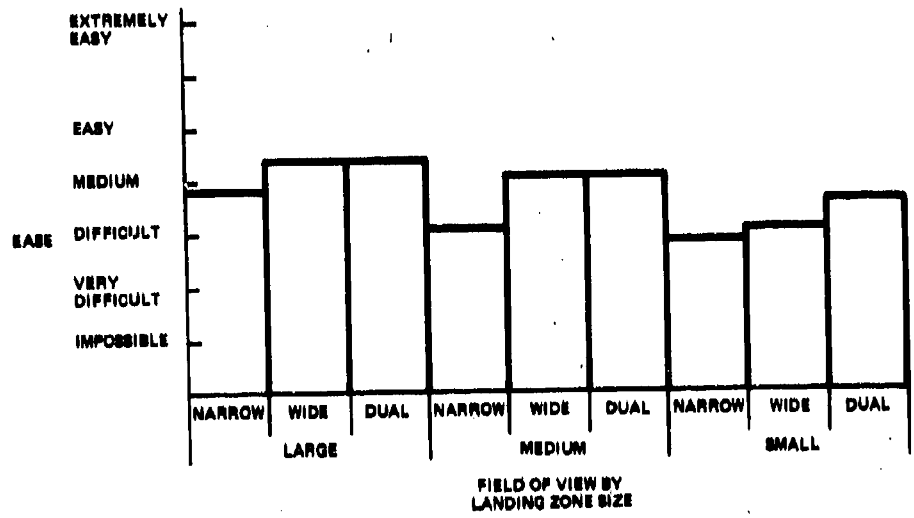

Figure 7-11. Ease of Landing

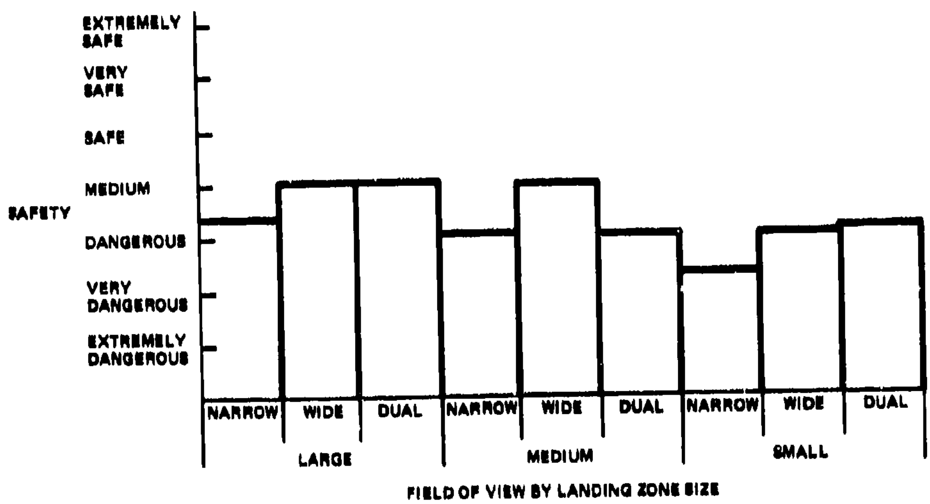

Figure 7-12. Safety of Landing

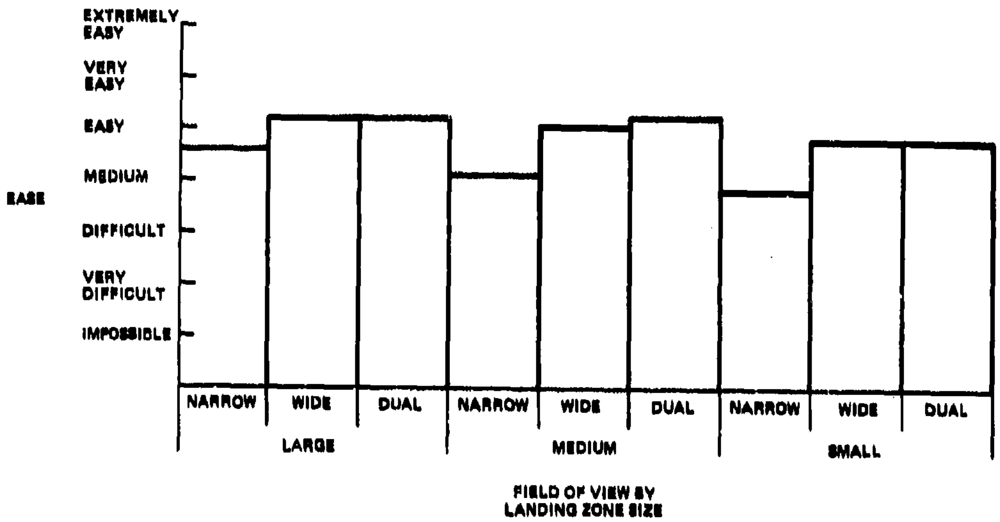

Figure 7-13. Ease of Takeoff

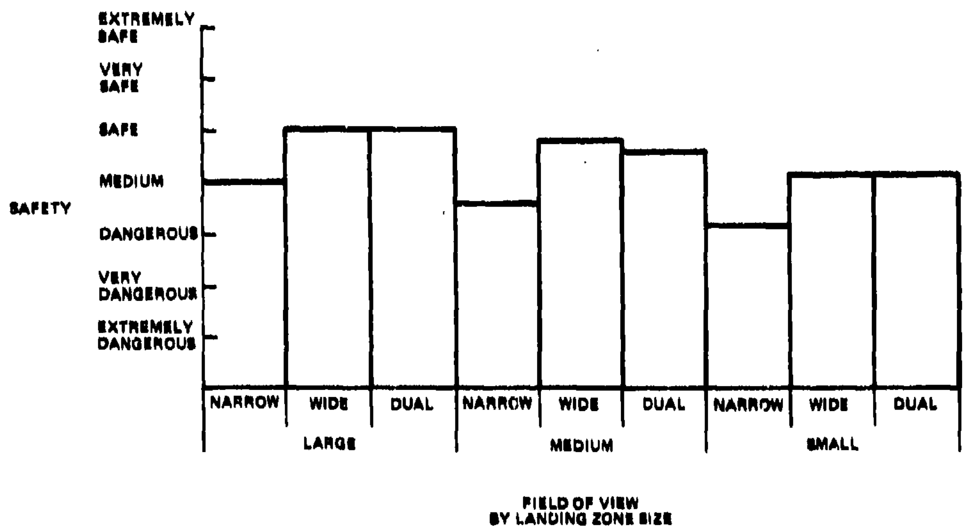

Figure 7-14. Safety of Takeoff

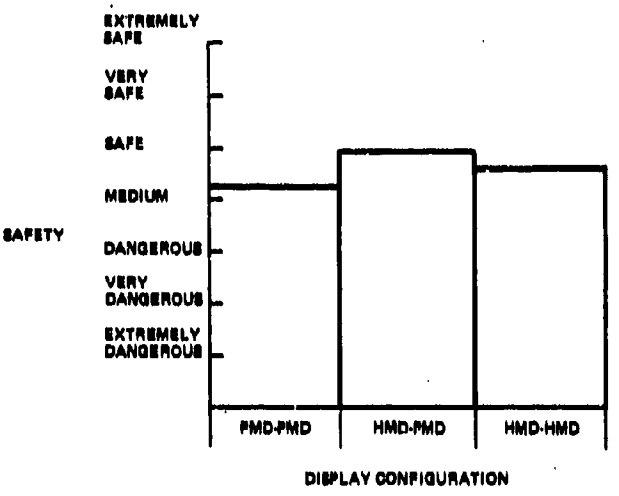

Figure 7-15. Safety of Approach to LZ

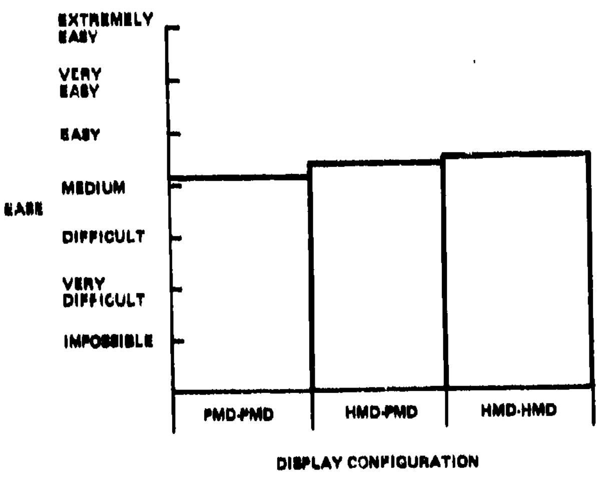

Figure 7-16. Ease of Approach to LZ

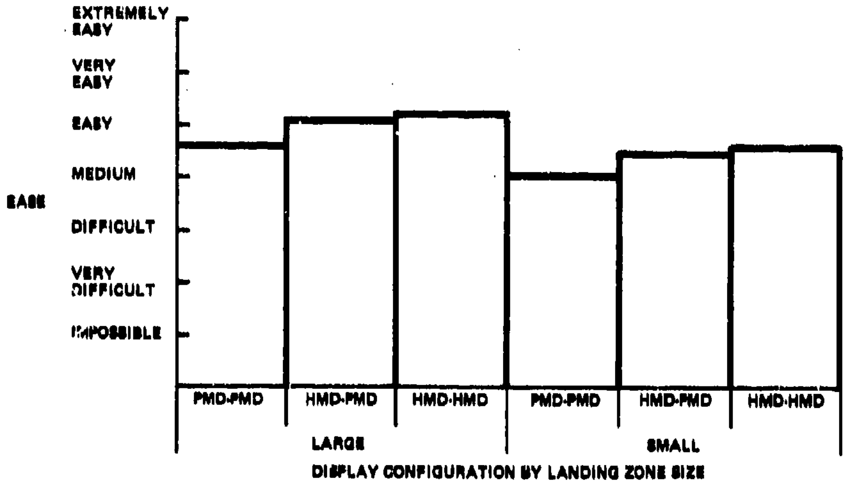

Figure 7-17. Ease of Landing

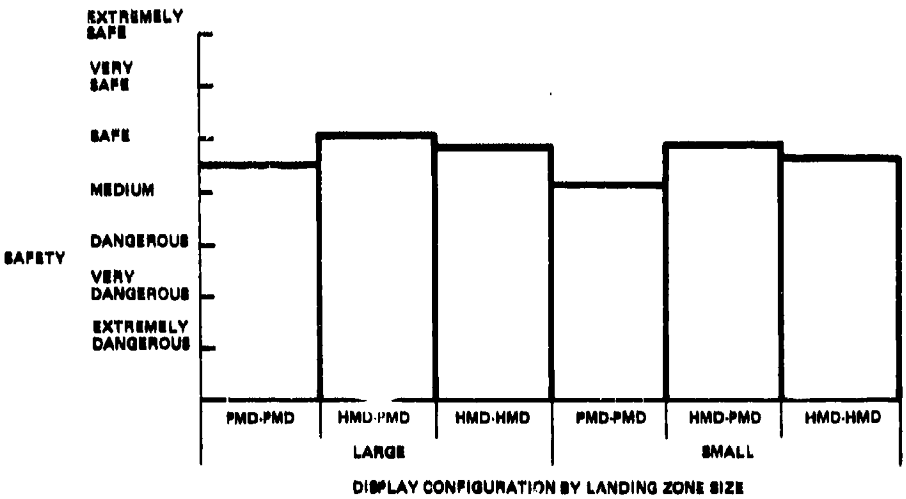

Figure 7-18. Safety of Landing

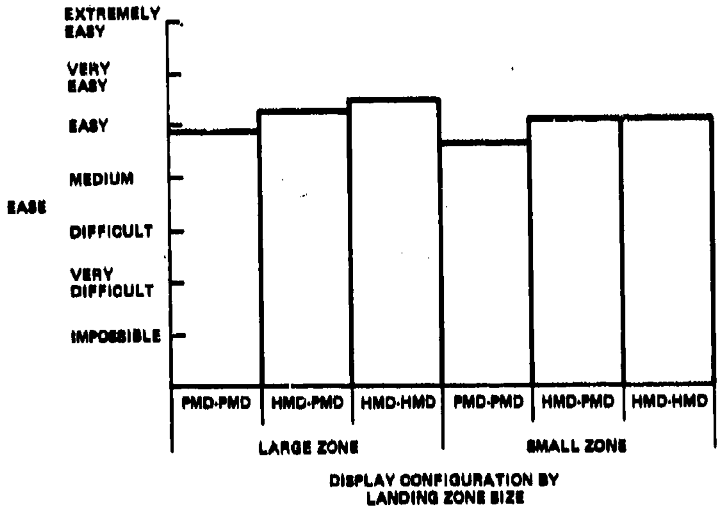

Figure 7-19. Ease of Takeoff

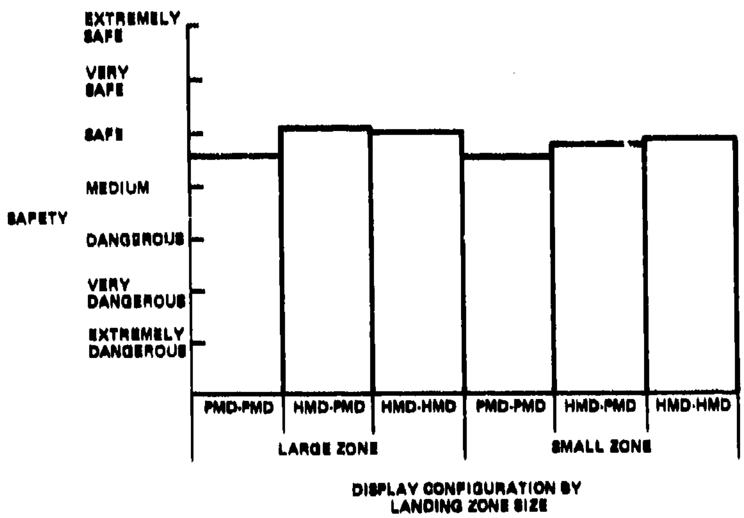

Figure 7-20. Safety of Takeoff

For landing in small zones, the HMD-PMD is rated significantly ($p < 0.10$) safer than the dual PMDs. The HMD-PMD also is rated significantly ($p < 0.05$) safer than the PMD-PMD combination during takeoff from the large zone. There was very little rating difference between HMD-PMD and HMD-HMD. However, the trend indicated a preference for the HMD-PMD for safety and the HMD-HMD for ease. This reflects the preference for having the copilot relatively free inside the cockpit in case of an emergency.

Participants were asked to indicate the minimum safe target altitude at 60 to 80 knots and the maximum safe target groundspeed at 50 to 100 feet AGL, which was attainable on an actual night mission. Table 7-III contains the responses according to display configuration and terrain type. Both HMD combinations had faster groundspeed ratings than the dual PMDs. The altitude ratings are more variable with the HMD-PMD tending to be slightly lower.

Comments made by three or more pilots in the approach and landing HMD-PMD evaluation phase were as follows:

1 Feel more comfortable as copilot on PMD than HMD (more visual cues)

2 Copilot controls PMD sensor slewing on approach and landings

3 PMD location acceptable

4 PMD size acceptable

5 HMD display size should be larger.

Additional questions addressed the issue of possible visual problems due to the cockpit lights and displays. Fifty percent of pilots flying with the HMD experienced visual problems with individual comments regarding the HMD as follows:

1 Tend to fixate on red panel lights (instrument panel lights dimmed)

2 Vertigo caused by moving too fast

3 Need finer brightness control

4 Put HDU on inboard eye to facilitate looking out window.

As copilot, 42 percent experienced visual problems. Individual comments regarding the HMD were as follows:

1 Hard to navigate with the HMD while functioning as copilot (two copilot comments)

2 Need dual sensors.

TABLE 7-III

Minimum Safe Altitude at 60 to 80 Knots and
Maximum Safe Speed at 50 to 100 Feet AGL

TERRAIN	RADAR ALTITUDE (FT) AND SPEED (KN) BY DISPLAY CONFIGURATION					
	PMD-PMD		HMD-PMD		HMD-HMD	
	ALTITUDE	SPEED	ALTITUDE	SPEED	ALTITUDE	SPEED
FLAT	68.54	87.5	66.45	90.83	68.95	87.08
ROLLING HILLS	98.54	73.33	101.04	74.16	105.41	71.25
MOUNTAINOUS	120.22	52.08	103.86	55.0	115.68	62.91
OVERALL MEAN	95.76	70.97	90.45	73.33	96.68	73.75

For effectiveness and safety, 67 percent preferred the HMD-PMD configuration and 33 percent the dual PMDs.

7.5 Enroute HMD-PMD-CDU Evaluation

Seventy-five percent of the pilots felt enough time was spent training on the display combinations. The majority of the pilots felt the field of regard was adequate for the transport mission. Regarding the field of view, 38 percent felt it was okay for terrain following, 50 percent indicated it was okay for navigation, and 63 percent said it was okay for checkpoint and landing zone identification. Twenty-five percent indicated they rarely or never use the narrow field of view. The wide field of view was acceptable for terrain following (63 percent), navigation (75 percent), checkpoint identification (75 percent), and LZ identification (75 percent). Twenty-five percent preferred the wide field of view in all situations.

In rating the ease and safety of the display configurations, the HMD-PMD was consistently safer and easier than either the HMD-HMD or PMD-PMD. Although the variability is small, Figures 7-21 through 7-27 show the pilots' preference for HMD-PMD followed by HMD-HMD. The pilots' HMD display is apparently the critical, preferred feature.

Table 7-IV shows the pilot ratings of actual mission altitudes and speeds. They prefer the HMD-PMD (75 percent) for ease and safety, and believe lower altitudes and higher speeds are attainable with the pilot using the HMD.

Thirty-eight percent had contrast problems but were able to overcome them. Sixty-three percent expressed visual problems as pilot, such as resolution of the HMD, focusing inadequacy of the HMD, and limited cockpit vision with the HMD. Fifty percent of the copilots expressed problems of navigation and map reading while using the HMD. Eighty-eight percent considered the HMD-HMD combination to be the least effective and safe. They felt the HMD for the copilot was too restrictive and disorienting.

In evaluating the CDU, 62.5 percent of the pilots felt they received enough training. The CDU would have no effect on maintaining a low altitude according to 62.5 percent, while 75 percent responded that it would have no effect on groundspeed. The keyboard configuration resulted in problems for 62.5 percent. All the pilots (N=8) thought that the map display was an effective navigation tool. In the operation of the CDU modes, 87.5 percent had no problems. Thirty-eight percent expressed alignment problems with the line keys. Design changes expressed included a clear function for unwanted line keys, more precise line key to display alignment, and an option to initialize more than one directed point at a time while using the DIR MFK. Generally, the copilot was able to operate the CDU with little interruption in other copilot functions except verbal feedback and flight updates to the pilot. Figure 7-28 indicates the mission was rated significantly ($p < 0.05$) easier with the CDU. Figure 7-29 shows that using the CDU to change course would not increase the difficulty of the mission.

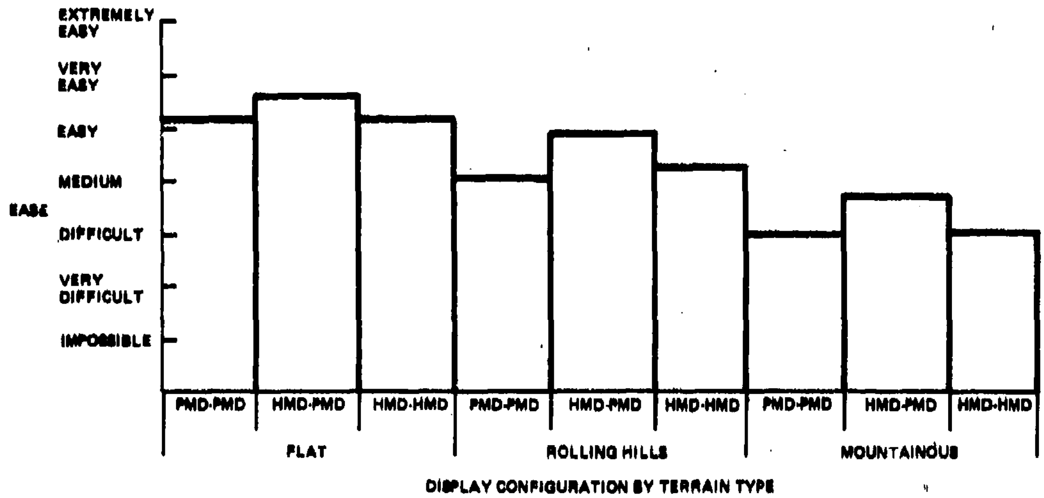

Figure 7-21. Ease of Actual Mission at 60 to 80 Knots and 100 to 150 Feet AGL

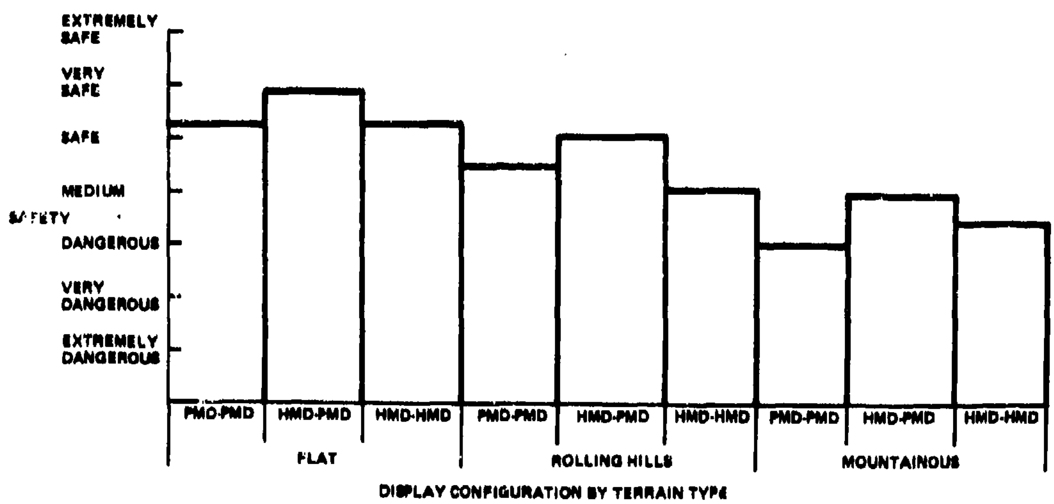

Figure 7-22. Safety of Actual Mission at 60 to 80 Knots and 100 to 150 Feet AGL

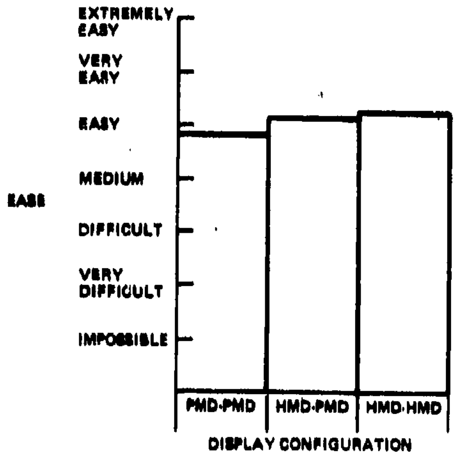

Figure 7-23. Ease of LZ Identification

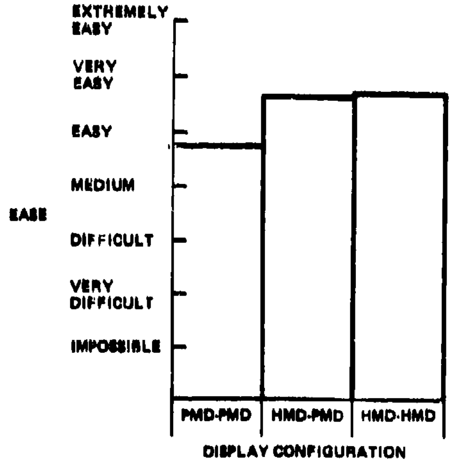

Figure 7-24. Ease of Checkpoint Identification

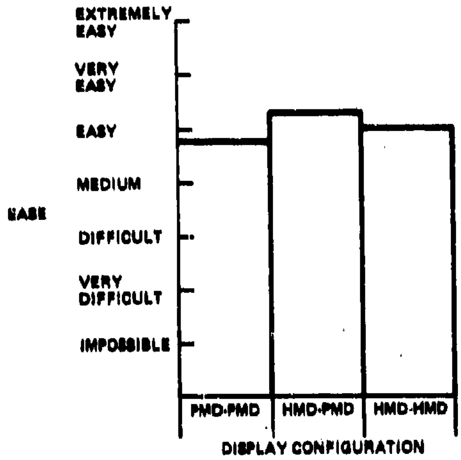

Figure 7-25. Ease of Navigation

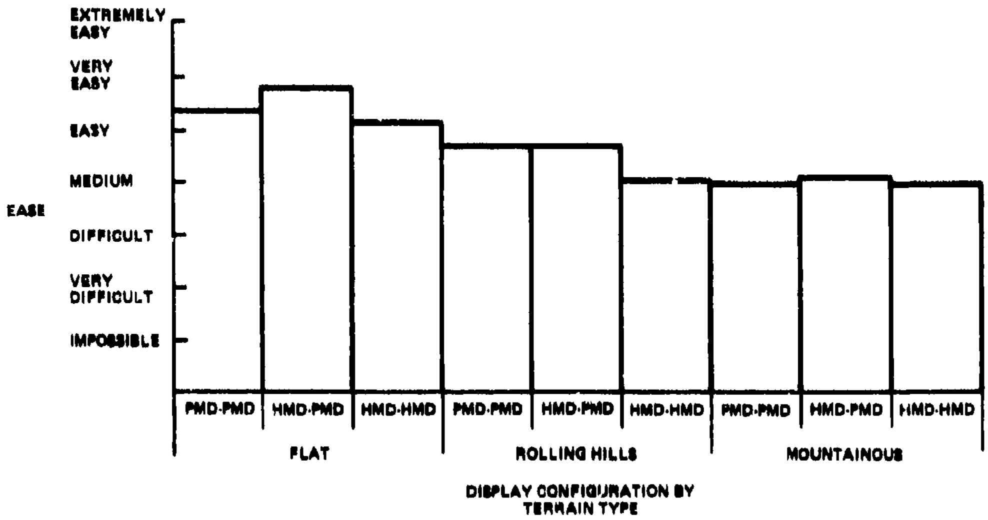

Figure 7-26. Ease of Terrain Following

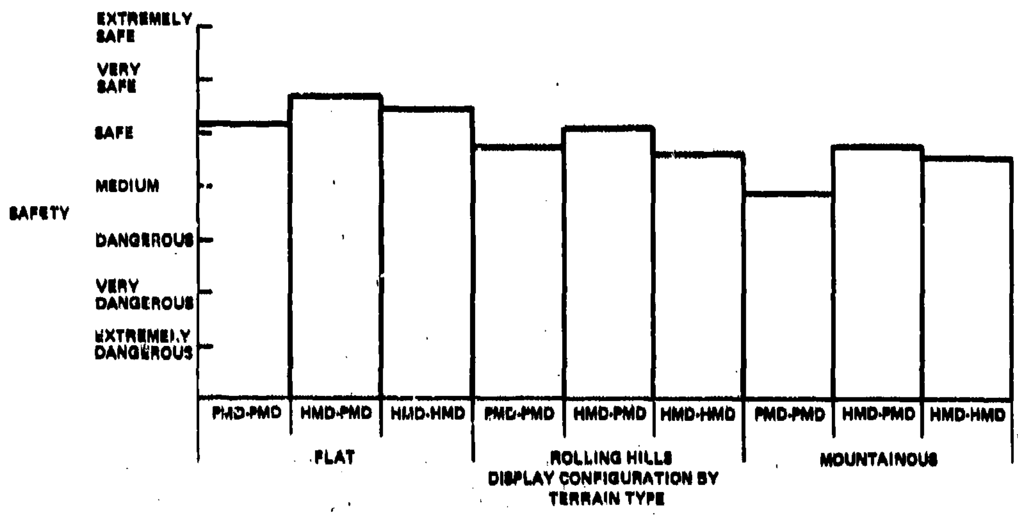

Figure 7-27. Safety of Terrain Following

TABLE 7-IV

Minimum Safe Altitude at 60 to 80 Knots and Maximum Safe Speed at 100 to 150 Feet AGL

TERRAIN	RADAR ALTITUDE (FT) AND SPEED (KN) BY DISPLAY CONFIGURATION					
	PMD-PMD ALTITUDE	PMD-PMD SPEED	HMD-PMD ALTITUDE	HMD-PMD SPEED	HMD-HMD ALTITUDE	HMD-HMD SPEED
FLAT	61.89	108.66	64.06	115.94	64.29	107.88
ROLLING HILLS	95.63	85.36	90.00	93.21	92.86	86.67
MOUNTAINOUS	143.44	62.86	129.38	66.43	122.14	63.33
OVERALL MEAN	100.32	84.93	94.46	91.86	93.10	85.95

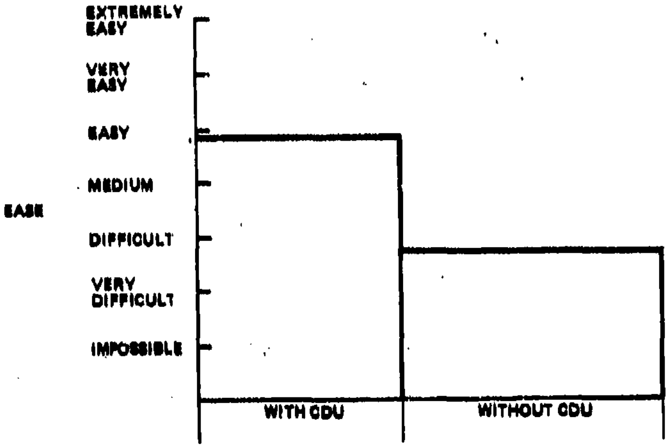

Figure 7-28. Ease of Actual Mission at 60 to 80 Knots and 100 to 150 Feet AGL

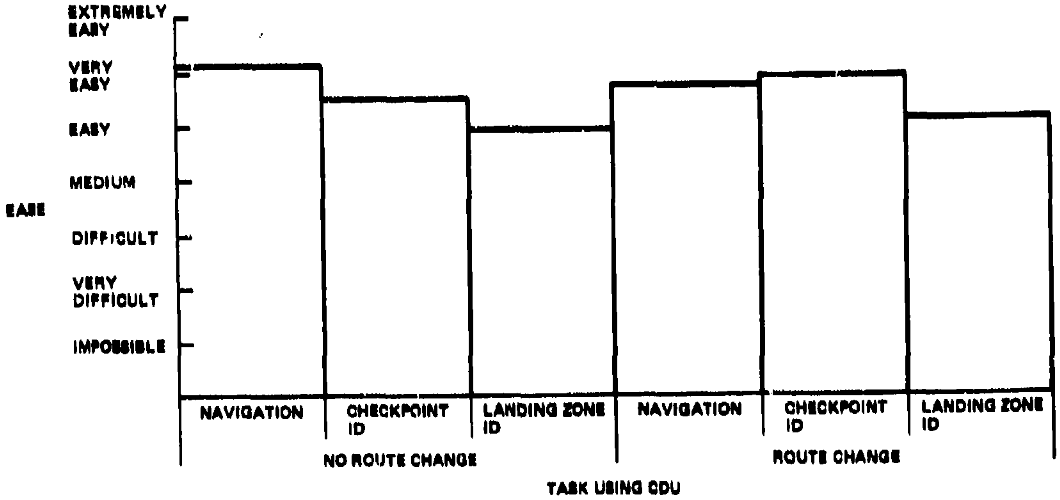

Figure 7-29. Task Ease with and without Course Change

7.6 Approach and Landing Virtual HUD Evaluation

All pilots (N=4) felt they obtained enough time training on the display combinations. Figures 7-30 through 7-35 show a significant ($p < 0.05$) preference for the HMD-PMD configuration followed by the HMD common video all aspects of the mission. Table 7-V indicates that pilots believe er altitudes and higher speeds are attainable with the HMD-PMD configuration.

All pilots felt the HMD-PMD combination was the most effective and safe because it frees the copilot for other duties and allows easy pilot sensor slewing. No pilot expressed display contrast problems, although two said the HMD caused eye strain and vertigo.

7.7 Enroute Virtual HUD Evaluation

Seventy-five percent of the participants believed enough training time was given. The pilots indicated the field of regard was adequate. The majority of pilots felt the wide field of view was adequate for the tasks required. Fifty percent felt the narrow field of view was too small for the transport mission.

Figures 7-36 through 7-42 show a consistent preference for the HMD-PMD configuration across all aspects of mission ease and safety. The HMD-HMD virtual HUD was considered the most dangerous and difficult display configuration. Table 7-VI indicates that the HMD-PMD configuration would result in lower altitudes and higher speeds than the dual HMD configurations. The pilots expressed a preference for the copilot PMD for the purposes of map reading and navigation. They felt the virtual HUD made it difficult to maneuver the head and use the CDU and that the time required to regain the display created a dangerous situation. All pilots felt the HMD-PMD was the most effective and safe configuration and the HMD- HMD virtual HUD the least effective and safe.

Additional comments by one or more pilots included:

1 The virtual HUD induced vertigo and did not allow a smooth scan

2 No contrast problems were experienced with the display combinations

3 A separate sensor is needed for the copilot

4 Panel mounted display location is perfect

5 The PMD does not restrict copilot head movements

6 Relocate HMD and communication wiring so as not to interfere with movements

7 The HMD is adequate, safe, and ideal for low light missions but PMD preferred.

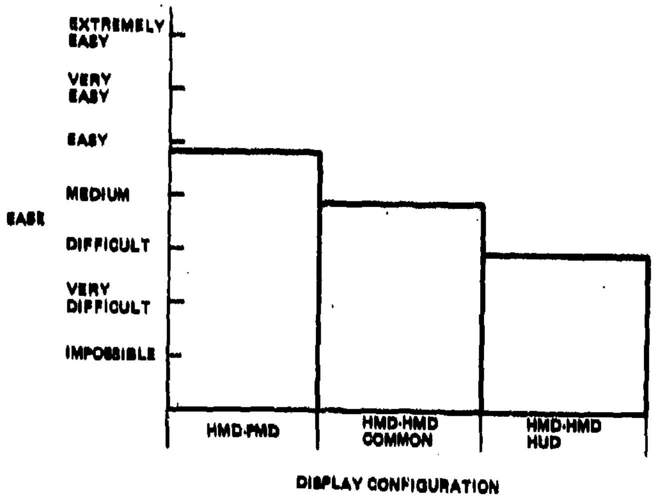

Figure 7-30. Ease of Approach to LZ

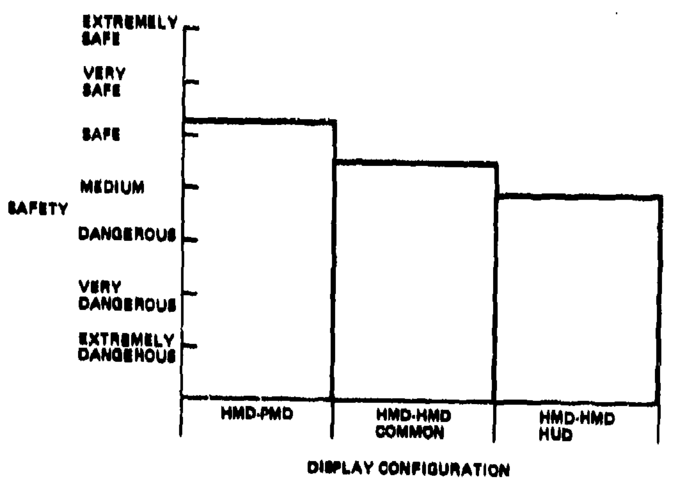

Figure 7-31. Safety of Approach to LZ

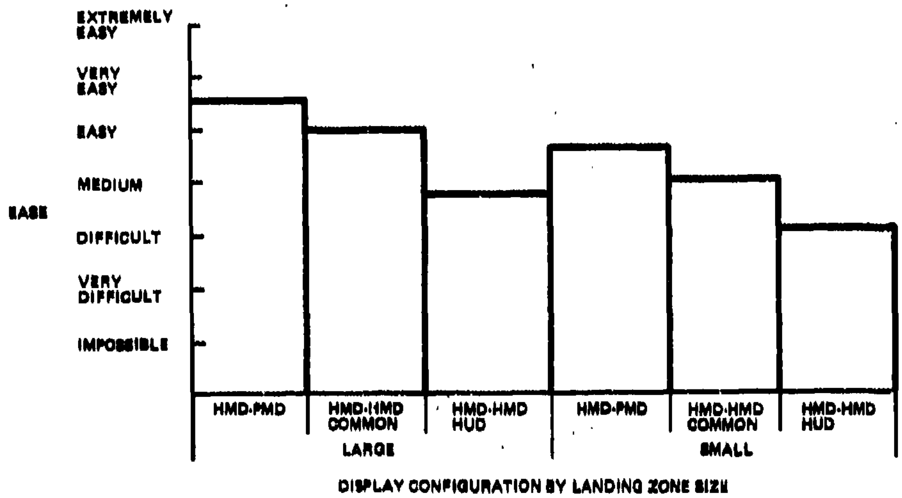

Figure 7-32. Ease of Landing

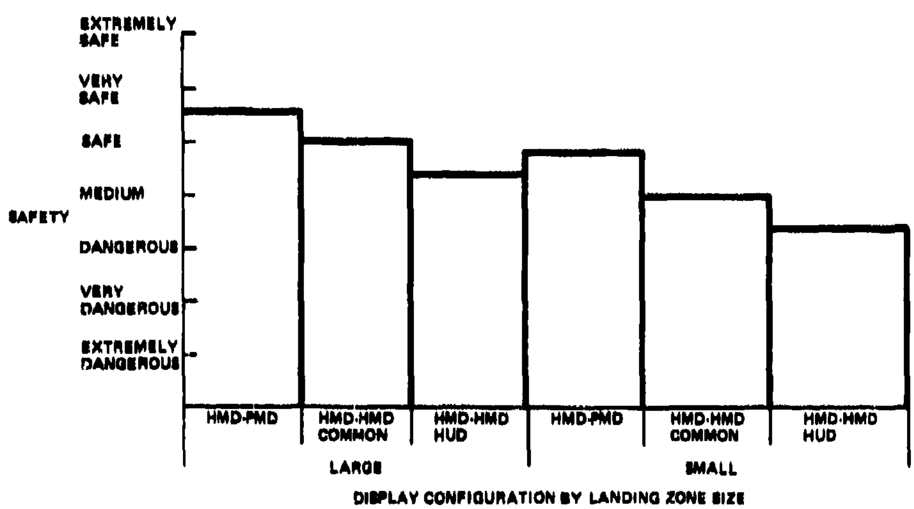

Figure 7-33. Safety of Landing

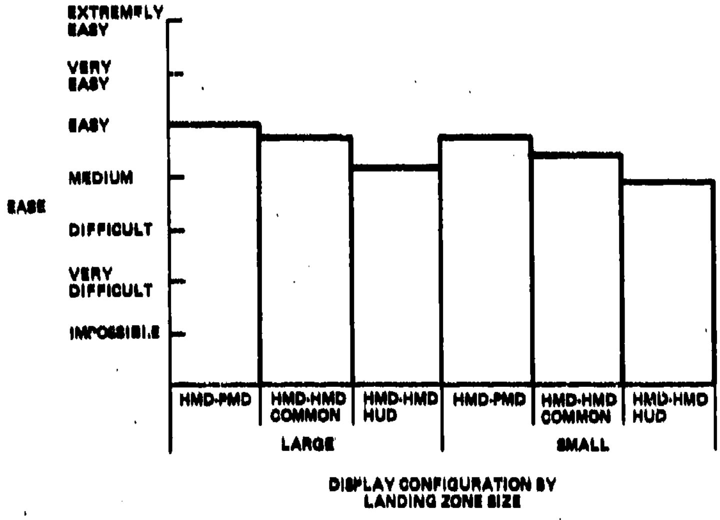

Figure 7-34. Ease of Takeoff

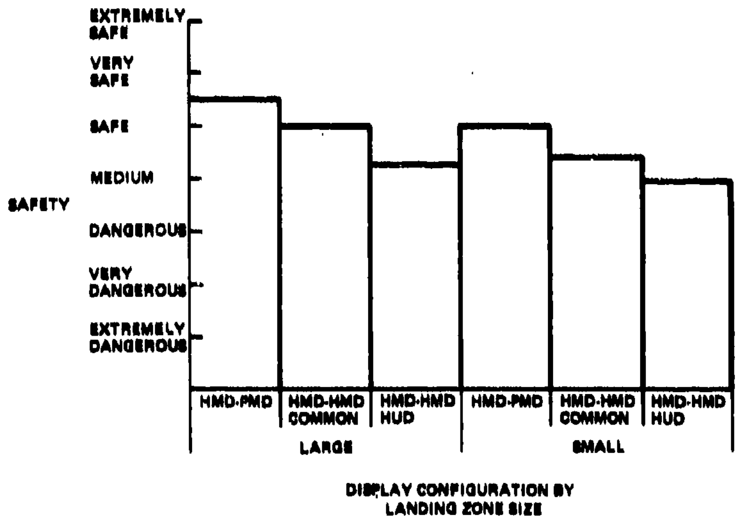

Figure 7-35. Safety of Takooff

TABLE 7-V

Minimum Safe Altitude at 60 to 80 Knots and
Maximum Safe Speed at 50 to 100 Feet AGL

TERRAIN	RADAR ALTITUDE (FT) AND SPEED (KN) BY DISPLAY CONFIGURATION					
	HMD-PMD		HMD-HMD (COMMON)		HMD-HMD (HUD)	
	ALTITUDE	SPEED	ALTITUDE	SPEED	ALTITUDE	SPEED
FLAT	82.0	87.5	93.75	82.5	103.75	73.75
ROLLING HILLS	108.75	77.5	113.75	71.25	123.75	66.25
MOUNTAINOUS	128.0	68.75	127.5	63.75	133.75	58.75
OVERALL MEAN	106.25	77.92	111.67	72.5	120.42	66.25

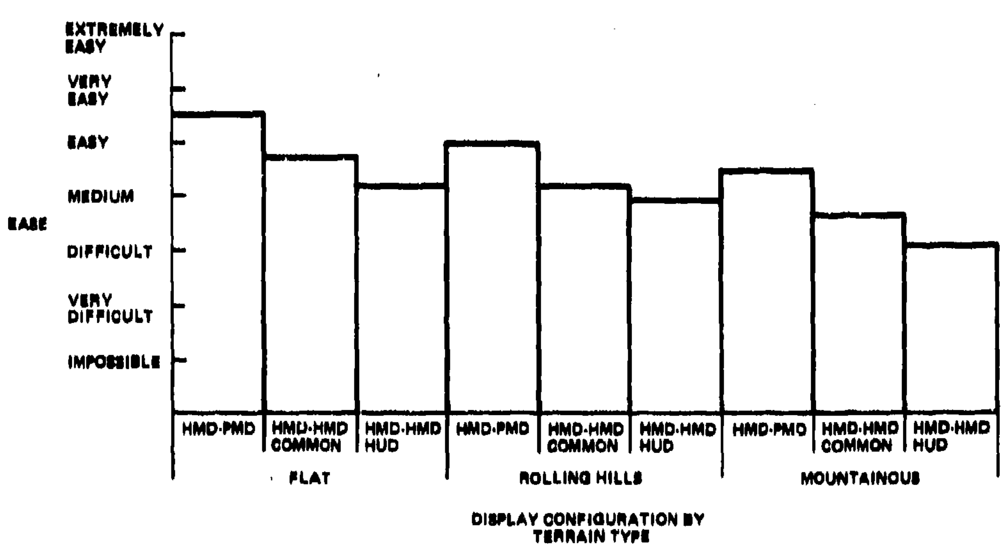

Figure 7-36. Ease of Terrain Following

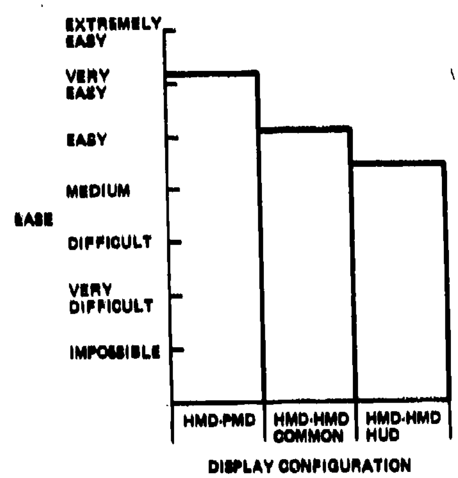

Figure 7-37. Ease of Navigation

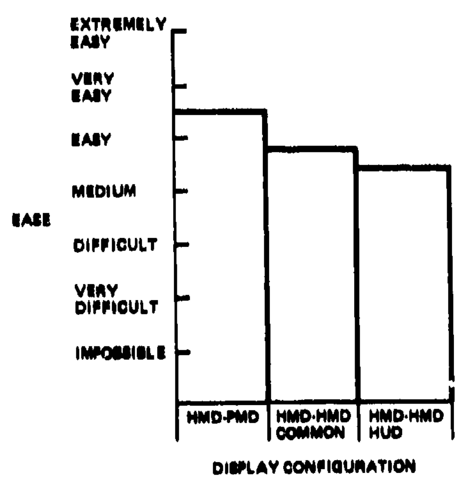

Figure 7-38. Ease of Checkpoint Identification

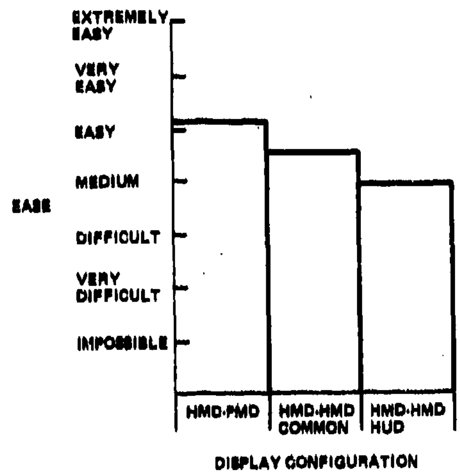

Figure 7-39. Ease of LZ Identification

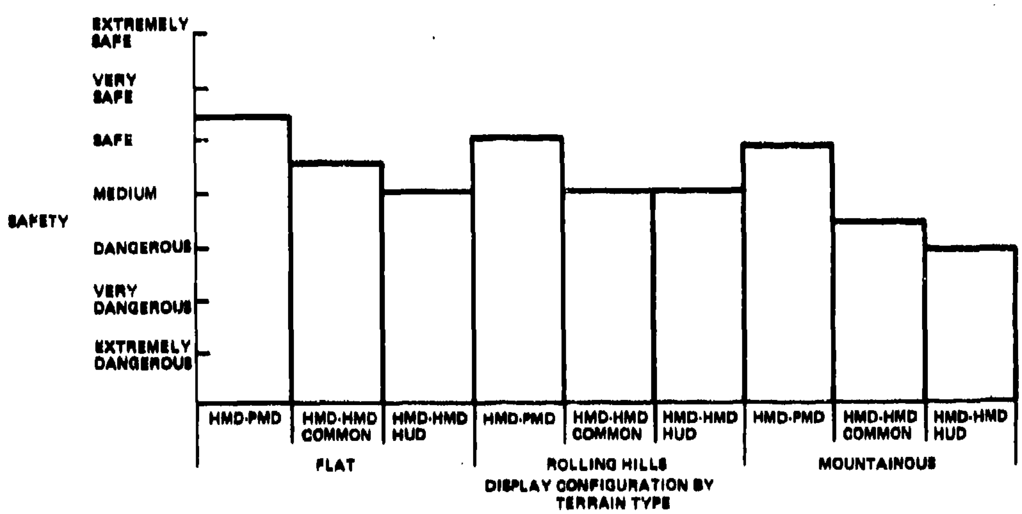

Figure 7-40. Safety of Terrain Following

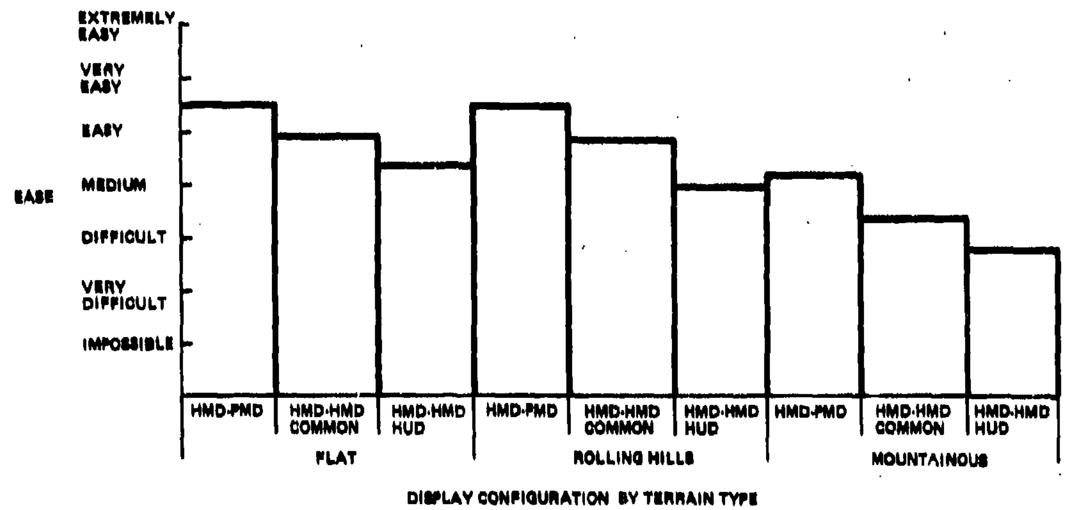

Figure 7-41. Ease of Actual Mission at 60 to 80 Knots and 100 to 150 Feet AGL

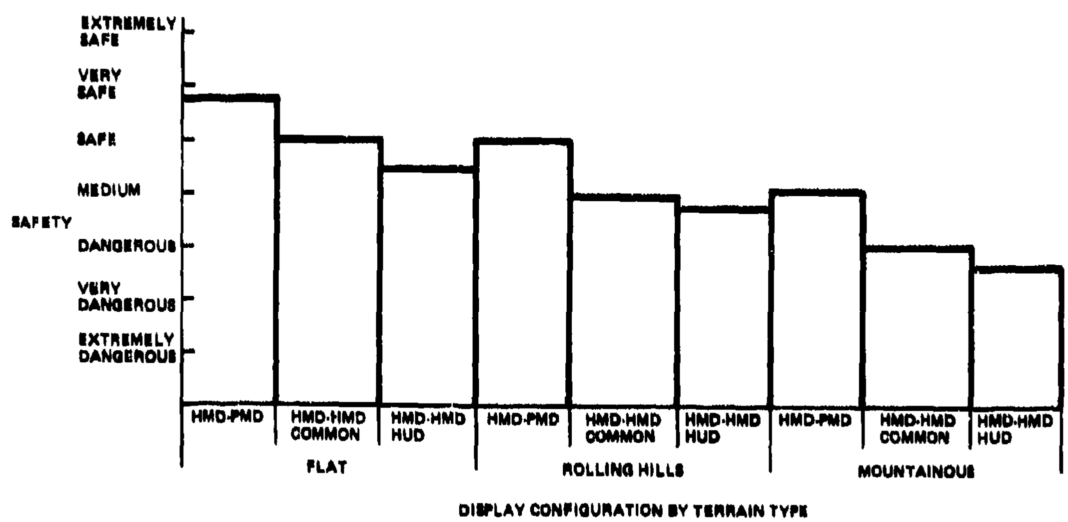

Figure 7-42. Safety of Actual Mission at 60 to 80 Knots and 100 to 150 Feet AGL

TABLE 7-VI

Minimum Safe Altitude at 60 to 80 Knots and
Maximum Safe Speed at 100 to 150 Feet AGL

TERRAIN	RADAR ALTITUDE (FT) AND SPEED (KN) BY DISPLAY CONFIGURATION					
	HMD-PMD		HMD-HMD (COMMON)		HMD-HMD (HUD)	
	ALTITUDE	SPEED	ALTITUDE	SPEED	ALTITUDE	SPEED
FLAT	112.5	90	130	82.5	138.75	78.75
ROLLING HILLS	120	71.25	138.75	65	147.5	61.25
MOUNTAINOUS	142.5	63.75	165	55	176.25	51.25
OVERALL MEAN	125	75	144.58	67.5	154.16	63.75

The actual mission was rated significantly ($p < 0.05$) easier with the CDU than without (Figure 7-43). When using the CDU, route changes do not make the mission tasks more difficult (Figure 7-44).

All the pilots felt they obtained enough CDU training. Seventy-five percent felt the CDU helped to maintain a low altitude, and 50 percent felt it helped to increase groundspeed. These respondents felt it eased navigation duties and increased orientation, which allowed more time for concentration on flight tasks. The majority of pilots experienced no keyboard problems or initialization problems with the different modes. The line keys did not cause great difficulty for most of the CDU users, once they solved their parallax problems. The copilots felt the tactical map display was useful. Initialization of the DIR function required the copilot to leave his flight scan, and the pilot workload increased momentarily.

7.8 Side Studies

Available time allowed the conduct of side studies in the major research schedule. However, these studies did not warrant full scale factorial designs, nor was there enough data to conduct any objective analysis. The following subjective summaries are based on four pilots for each evaluation.

7.8.1 Radar Analog Scale

The pilot opinion was mixed on the effects of removal of the radar analog scale during hover. Half of the pilots believed it cleaned up the screen and improved hover performance and half believed it degraded performance and required more scan. Pilot opinion in favor of the changes included improved midscreen scan for basic maneuvering. There was agreement on a preference for the radar altimeter readout in digital 1 foot increments below 25 feet.

7.8.2 Landing without the Simulated Crew Chief

Reaction was mixed on the requirement to land unaided by the crew chief. Half of the pilots felt that not having a crew chief had a moderately to greatly deteriorating effect on their ability to hover and land. The remaining pilots felt no effect, relying more heavily on symbology and skill of controlling the hover. Half believed that the sensor provided enough information to land easily and safely. These pilots relied more on slewing down than left or right. The other half felt the sensor landing created a dangerous and difficult condition. Scan patterns and crew interaction was not changed by not having a crew chief.

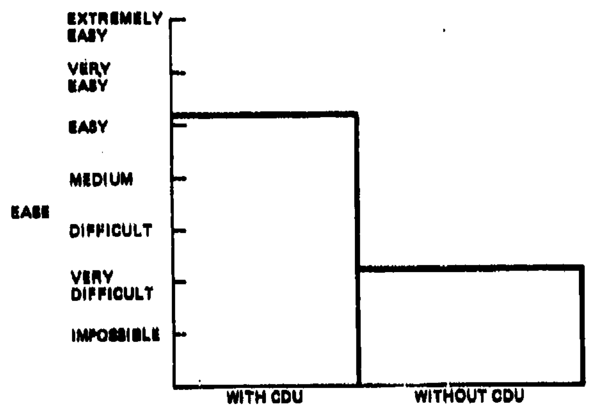

Figure 7-43. Ease of Actual Mission at 60 to 80 Knots and 100 to 150 Feet AGL

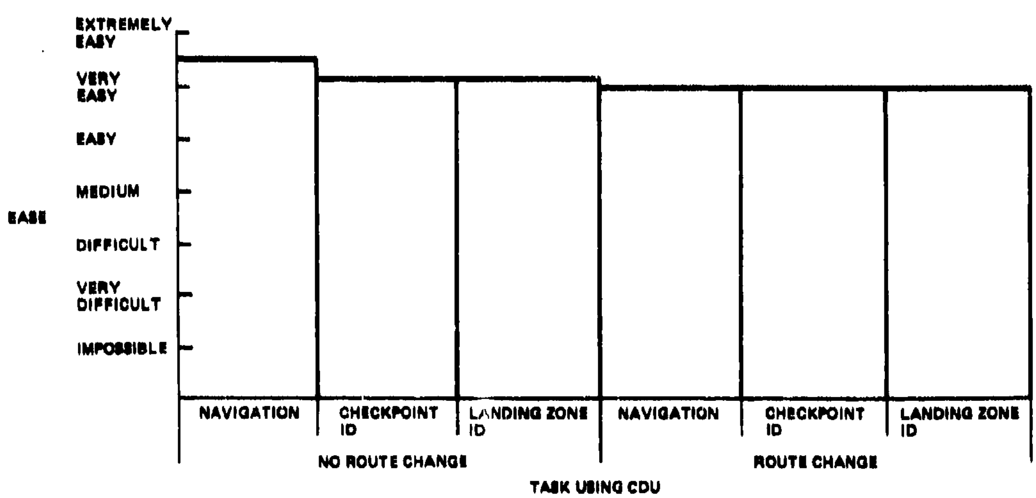

Figure 7-44. Task Ease with and without Enroute Course Change

7.8.3 Symbology Attitude Sized to the Wide Field of View

During flight, the pilots expressed some confusion regarding exactly what changes had been made. All pilots were favorable on their comments on the changes, but uncertain as to what those changes were. All the pilots felt that their performance improved greatly and that the visual feedback was much more realistic. They were able to fly with a more sensitive reaction to the terrain and symbology, at a lower altitude and faster speed. The actual flight differences were less than the subjective differences. The average altitude was 67 feet for sized symbology and 66 for the unchanged. The average groundspeed was 76 knots for the sized symbology and 69 knots for the unchanged.

7.8.4 Partial Ground Stabilized Sensor versus Aircraft Stabilized Sensor

Seventy-five percent of the pilots preferred the ground stabilized sensor for the final landing phase to provide a constant view of the zone. The pilots indicated a slight preference for the pilot using an HMD, followed by ground stabilized PMD sensor, and aircraft stabilized, respectively. This group of pilots learned to fly with the HMD and were thus more familiar with this system. They were not accustomed to the manual slew and equated the ground stabilized mode to the HMD (i.e., the pilot keeps his head fixed on the landing zone).

7.9 Modified Cooper-Harper Ratings

The modified Cooper-Harper (C-H) rating scale was designed to assign a numerical value to the pilot's judgement of overall field of view and HNVS acceptability. Figure 7-45 represents the scaling codes.

Table 7-VII indicates the mean field of view ratings. The narrow field of view is significantly ($p < 0.05$) less acceptable than the wide or dual.

Table 7-VIII contains the mean display acceptability ratings with and without the CDU. The HMD-PMD configurations with the CDU is the most acceptable configuration for enroute mission compatability. The pilots felt the helicopter with this configuration could be flown below 100 feet at greater than 60 knots with a moderate workload.

Table 7-IX indicates pilot ratings of the virtual HUD evaluation configurations. Again the HMD-PMD with a CDU received the best rating. Both HMD pilot groups (Tables 7-VIII and 7-IX) considered the HMD-PMD configuration to be the most acceptable configuration with and without the CDU. In Table 7-X, the pilots indicated a higher acceptability rating for approach and landing with the HMD-PMD.

7.10 Summary

Pilot opinions were generally favorable toward simulation facilities. The participants quickly learned the requirements and the operation of the

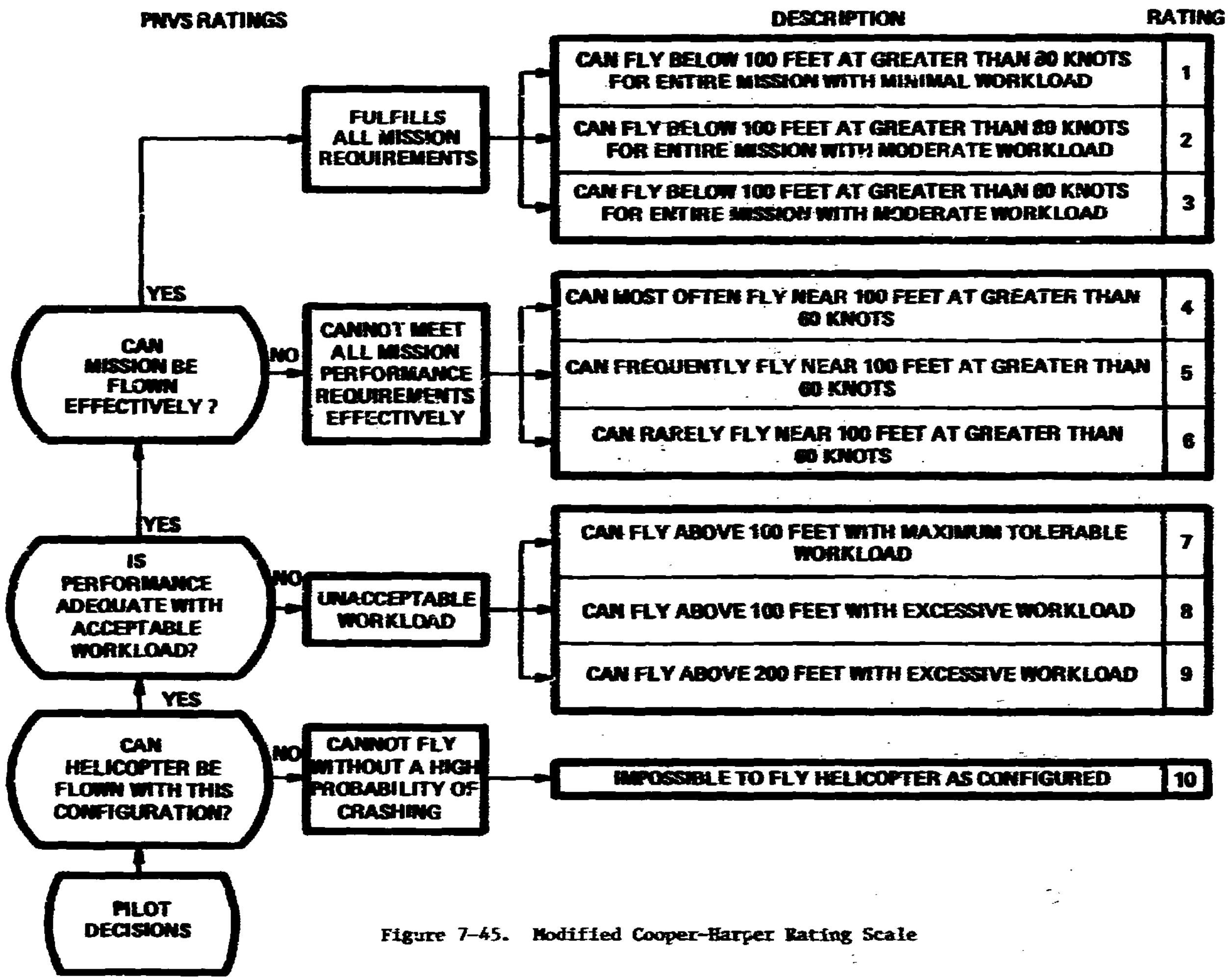

Figure 7-45. Modified Cooper-Harper Rating Scale

TABLE 7-VII

Cooper-Harper Rating:
Enroute FOV

FIELD OF VIEW	MEAN RATING
NARROW	6.45
WIDE	3.41
DUAL	4.22

TABLE 7-VIII

Copper-Harper Rating:
Enroute Display/CDU

DISPLAY	MEAN RATING	
	WITH CDU	WITHOUT CDU
PMD-PMD	3.43	6.5
HMD-PMD	3.00	6.25
HMD-HMD	3.50	7.00

TABLE 7-IX

Copper-Harper Rating:
Enroute Virtual HUD/CDU

DISPLAY	MEAN RATING	
	WITH CDU	WITHOUT CDU
HMD-PMD	3	4.25
HMD-HMD (COMMON VIDEO)	4	5.25
HMD-HMD (VIRTUAL HUD)	6	7.00

TABLE 7-X

Copper-Harper Rating:
Approach and Landing

DISPLAY	MEAN RATING
HMD-PMD	2.5
HMD-HMD (COMMON VIDEO)	4.0
HMD-HMD (VIRTUAL HUD)	5.5

simulator. Pilots with more CH-53 experience had a more difficult time learing to fly the simulator than those with less CH-53 experience.

Most pilots found all the necessary flight information on the PMD and used the instrument panel as occasional backup. The turn and slip indicator was frequently the instrument the pilots desired on the PMD. They had difficulty learning the use of the velocity vector because they were using it at first only as a turn and slip indicator.

All pilot groups believed the training packages and procedures were advantageous. Several groups requested learning to hover and land prior to learning the flight symbology. The pilots felt it would be beneficial to learn to control the simulator in a hover prior to learning the flight requirements.

The symbology evaluation was generally favorable to the flight symbology set during approach and takeoff. For landings, trends indicate a preference for the hover symbology set followed by the hover meter.

The wide and dual fields of view were preferred over the narrow. Wide and dual resulted in little subjective variability.

The HMD-PMD evaluation resulted in a definite preference for the pilot to have a helmet display. The copilot preferred an HMD for mission ease and a PMD for mission safety. The enroute evaluation indicates a consistent preference for the HMD-PMD configuration.

The copilot felt that the virtual HUD configuration was more difficult and dangerous than the common HMD video or HMD-PMD configurations. Again, the HMD-PMD was the preferred display configuration.

The CDU was found to be an extremely useful navigation tool. It enables the copilot to accurately assess present position, desired position, and overall mission. The HMD increased the copilots task loading, but operation of the CDU was still possible.

The related studies indicated that the symbology attitude should be sized to the wide field of view with the pitch ladders set at 5 and 10 degrees. The pilots still desire some changes in the radar altitude configuration but not necessarily the ones examined. If the PMD is used for the pilots display, then the ground-stabilized option is benefical.

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(Phases I and II)

8.0 CONCLUSIONS

The simulation experiments ~~have~~ demonstrated the ability of the pilot and copilot to fly a night mission at low altitudes, ranging from 50 to 150 feet AGL, in a CH-53D simulation with the night visionics equipment package described previously. ~~Prior~~ HNVS simulation studies ~~(Phases I and II)~~ indicated that enroute flight profiles over the simulator's rolling terrain can be accomplished at airspeeds ranging from 60 to 80 knots with clearance altitudes averaging 100 feet. This study was conducted with a revised terrain model with improved altitude feedback cues that produced higher clearance altitudes and somewhat lower airspeeds than the prior simulations. The actual speeds and altitudes will be verified in the planned HNVS flight tests. The simulation confirmed the minimum system requirement of a gimballed FLIR with a navigation system and with ancillary hardware such as a symbol generator.

Although this experiment required no data be generated on dead reckoning versus navigation system requirements, both pilot performance and opinion data reiterated the reduced crew station workload with Doppler command steering information. The incorporation of the navigation capability of the CDU also was instrumental in further reducing the navigation workload.
(Control Display Unit)

Data did reaffirm crew interaction and extensive training as critical to mission success. Crew tasking is not as well defined for this experiment as in Phases I and II. Phases I and II data showed the pilot at the control of the aircraft to be the primary sensor operation when using the PMD. Each pilot group for this experiment was briefed recommending the Phases I and II tasking procedure. The majority of the pilot groups during these phases found their best performance with the pilot in control of the sensors. A few groups experimented with crew tasking, however, and allowed the copilot total sensor control with the pilot required to request sensor usage. Also, some crews allowed the copilot to slew the sensor enroute after warning the pilot but never allowed the copilot to slew in a hover. In essence, the night transport mission appears to be a two pilot task with a constant verbal exchange between pilots. The best performing pilot groups appeared to be those where the pilot controlling the aircraft was also the primary sensor operator.

The hover symbology set resulted in the most stable approach profile and successful landing results. The symbology evaluation indicated the flight symbology provided sufficient piloting information to maintain aircraft control during the initial approach phase. Most pilots chose to bring up the transition hover symbology at approximately 35 knots and 0.3 nmi from the touchdown point. The horizontal presentation of the transition hover symbology provided additional information for continued aircraft

deceleration in preparation for establishing a hover. Most pilots chose to bring the aircraft to almost a hover (approximately 5.0 knots) before bringing up the hover symbology. The increased gains and hover position symbol available with hover symbology allowed the pilots to precisely establish a hover and to mark their intended point of touchdown prior to landing.

The pilots did not find the 25 degree narrow FOV more useful for generating additional information on checkpoint identification or accessing the landing zone than the visual information provided by the 50 degree wide FOV. Although continually encouraged by the experimental team to use the narrow FOV, the pilots indicated a clear preference to the wide FOV. The single, wide FOV appears to provide sufficient information for the night transport mission.

The majority of pilots preferred flying the night transport mission with the HMD over the PMD regardless of which display configuration the copilot was using. The precise slewing of the sensor with the HMD as commanded by the pilot's natural head movements allowed control of the sensor without changing hand position on the collective during critical flight maneuvers as required when operating the sensor manually on the PMD. Additionally, the one-to-one visual presentation available with the HMD provided increased visual feedback over the minification present on the PMD.

The majority of copilots preferred using the PMD over HMD. They found the constant moving imagery somewhat distracting when performing the CDU line key and master function tasks.

The copilot group evaluating the virtual HUD mode of IHADSS did not find this mode useful. Of particular concern was the copilot's loss of symbolic aircraft attitude and altitude information and loss of imagery while performing cockpit tasks using the virtual HUD.

The preferred cockpit display configuration was with the pilot using the HMD and the copilot using the PMD. The HMD provides the pilot with precise slewing control over the sensor and more visual feedback information than available with the PMD. The PMD provides the copilot with sufficient aircraft position and attitude and altitude information, yet allows ease of cockpit workload tasks without visual interference while using the HMD or complete loss of aircraft information while using virtual HUD.

The copilots found the CDU to be a useful navigational aid in reducing the navigation workload task. The present keyboard inputs required for enroute changes, however, are somewhat cumbersome because of the nonalignment of the CDU symbology and the appropriate line keys. This resulted in copilot confusion and numerous copilot input errors. The lack of an indication for positive CDU line key actuation also resulted in numerous copilot line key input errors.

On longer enroute navigation legs, the copilots were required to continually change the CDU tactical map display scale, or to manually recenter the scale to prevent the helicopter symbol from disappearing off the edge

of the CDU display. Consideration should be given to providing an automatic scale change or recentering capability of the CDU map mode.

The CDU keyboard lighting function is presently coupled to the nonflight instruments rheostat. When the nonflight instruments were dimmed to low intensity levels and were still readable by the copilot, the CDU keyboard lighting vanished. Also, the CDU keyboard lighting is white, whereas all other cockpit instrument lighting is red. Consideration should be given to providing a separate lighting rheostat for the CDU keyboard and to changing all lighting in the cockpit to the same color.

Pilots tended to slew the sensor more frequently in azimuth and elevation than observed during Phases I and II. When using the PMD the majority of usage in azimuth was within 15 degrees of centered line of sight. Infrequent usage was observed in azimuth to 60 degrees of centered line of sight. The majority of usage in elevation was to look down within 35 degrees of centered line of sight. Infrequent usage was observed in elevation to look down to 60 degrees of centered line of sight. The pilots never intentionally slewed the sensor up while using the PMD. Sensor usage increased when the pilots returned to using the PMD after learning to slew the sensor with the HMD. Reaffirming the sensor usage observed during Phases I and II, it appears a minimum of 45 degree sensor field of regard in azimuth and 15 degrees up and 40 degrees down in elevation should be adequate for the entire enroute, approach, and landing phases of the night transport mission.

The pilots indicated that sizing the symbology to the wide FOV aided in more precise pitch attitude control of the aircraft.

The pilots indicated that the corridor line and altitude reference bar was not useful for the night transport mission.

The majority of the pilots indicated the digital presentation of torque was sufficient for power management and the graphical presentation of torque was not required.

The pilots indicated that the digital presentation of radar altitude would be more useful for low altitude control if presented in units below 25 feet AGL.

The pilots found the point of interest marker to be extremely useful as a communication tool.

Several pilots indicated the need for an aural low altitude warning system below 50 feet AGL.

The pilots indicated a requirement for a sideslip (ball) symbolic indication to minimize yaw angles while maneuvering.

The pilots seldom used the backup instruments since this experiment incorporated no failure analysis of symbology. Consideration should be given, however, to the proper arrangement of backup instruments and proper lighting intensity control.

The side study pilot group evaluating the partial ground stabilized sensor indicated a reduction in workload required to keep the landing zone in sight while maneuvering the aircraft during the approach phase. This data group was too small to make a positive judgement on the total value of the partial ground stabilized sensor to the night transport mission. This requirement should be evaluated during flight test.

Several pilots indicated the manual sensor slew control sensing was backward. The majority of pilots, however, preferred the existing configuration in which upward movement of the control slews the sensor upward.

9.0 RECOMMENDATIONS

9.1 Recommended HNVS Configuration

The recommended minimum HNVS configuration for flight test evaluation is a Doppler navigation system, gimballed sensor (+45 degrees azimuth, and 15 degrees up and 40 degrees down elevation), display configuration with pilot on HMD and copilot on PMD, and a single 50 degree FOV. Since the night transport mission is envisioned to be of long duration, the cockpit display configuration will require both pilot seats to be equipped with HMDs and PMDs to allow an exchange of pilot/copilot duties and to reduce crew station fatigue.

9.2 Symbology

The following changes in symbology are recommended prior to flight test:

1 Incorporate the hover symbology set including the transition hover symbology

2 Do not incorporate the virtual HUD mode in the IHADSS

3 Size the symbology (attitude) to the wide 50 degree FOV

4 Eliminate the corridor line

5 Eliminate the altitude reference bar

6 Eliminate the graphical presentation of torque

7 Present the digital radar altitude presentation in units below 25 feet AGL

8 Incorporate a symbolic sideslip (ball) presentation.

9.3 Controls and Displays

The following changes in controls and displays are recommended prior to flight test:

1 Realign the CDU symbology with the appropriate line keys

2 Provide a positive indication for CDU key actuation

3 Provide a separate rheostat for the CDU keyboard lighting function

4 Evaluate an automatic scale change or recentering capability for the CDU map mode during flight tests

5 Provide CDU keyboard lighting of the same color as the remaining cockpit instruments

6 Provide a low altitude warning system below 50 feet AGL

7 Provide cockpit backup instruments with consistent lighting intensity control

8 Evaluate the partial ground stabilized sensor requirement during flight test

9 Evaluate the manual sensor slew control sensing activity during flight test.

9.4 Crew Tasking

Evaluate the crew tasking allocations during flight test to determine minimum crew station workload.

APPENDIX A
CH-53 HNVS SIMULATION
GFE LIST

Item No.	Quantity	Description
1	1	Complete CH-53 Simulation Cockpit, Drawing Number 51579000, Rev. A
2	2	Slew Controller with Centering Switch, Model No. 485
3	1	HNVS Control Panel
4	2	EADI Control Panels
5	1	HIS Fail Panel
6	1	Control and Display Unit (CDU) Part No. 622-2698-001
7		Helmet Sight and Display System (IHADSS) Consisting of:
	1	Display Electronics Unit (DEU) Part No. BG1113AA01, S/N Q7
	1	Sight Electronic Unit (SEU) Part No. BG1142AA01, S/N Q1
	1	Display Adjust Panel (DAP) Part No. CG1082AA01, S/N Q14
	1	Boresight Reticle Unit (BRU) Part No. JG1099AA01, S/N R14
	2	Sensor Survey Unit (SSU) Part No. LG1127AA01, S/N Q26, Q29
	1	Helmet Display Unit (HDU) Part No. HG1041AA02, S/N R14
	2	Integrated Helmet Unit (IHU)

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ABBREVIATIONS

AFCS	automatic flight conrol system
AGL	above ground level
ANOVA	analysis of variance
BMDP	biomedical data package
C-H	Cooper-Harper
CDU	control display unit
DIR	direct-to
FLIR	forward looking infrared
FTL/PLN	flight plan
FTP	fly-to-point
FOV	field of view
HDU	helmet display unit
HIS	helicopter integration system
HMD	helmet mounted display
HNVS	Helicopter Night Vision System
HUD	head up display
IHADSS	Integrated Helmet and Display Sight System
IRDS	infrared detection system
LOS	line of sight
LZ	landing zone
MFK	master function key
NAV/EADI	Navigation/Electronic Attitude Director Indicator

PDG	programmable display generator
PMD	panel mounted display
SAS	stability augmentation system
SPURS	Special Purpose Rotorcraft Simulator
STL	Simulation and Test Laboratory